

# Wisconsin's Greenhouse Gas Emissions

Trends from 1990 to 2000



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**Author**

***Sara Kerr***

**Editor**

***Eric Mosher***

**Wisconsin Department of Natural Resources  
Bureau of Air Management  
PO Box 7921  
Madison, WI 53707**

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## EXECUTIVE SUMMARY

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Climate change is a global phenomenon with the potential to unleash a myriad of economic, social, and environmental problems on nations and citizens unprepared for the possible consequences. To understand the potential impacts of climate change and evaluate possible mitigation options, it is first necessary to assess its causes. The purpose of this report is to identify and quantify greenhouse gas emission sources in the state of Wisconsin which have the potential to contribute to climate change. This task was accomplished by utilizing the State Inventory Tool software provided by the U.S. Environmental Protection Agency. The software was developed based on new guidelines adopted by the Intergovernmental Panel on Climate Change, and is consistent with methods used to conduct the U.S. greenhouse gas emission inventory prepared by the U.S. Environmental Protection Agency.

The primary contributors to the climate change phenomenon are greenhouse gases (GHGs) in the atmosphere which absorb energy, thereby retaining heat in the atmosphere and warming the planet. The greenhouse gases of greatest concern are carbon dioxide, methane, nitrous oxide, and halogenated substances. Emissions of these gases in Wisconsin were quantified for the years 1990-2000 by gas, activity sector, and economic sector.

Initial results for the year 1990 were compared to those reported by the Wisconsin DNR in an earlier report (WDNR 1993). Significant differences were seen in estimates for the energy and agriculture sectors. However, these differences were traced to the accounting strategies and methodologies used. Estimates from the two studies were found to be within 4% after compensating for differences.

Total net greenhouse gas emissions in Wisconsin were 107.6 million metric tons of CO<sub>2</sub> equivalent (MMTCO<sub>2</sub>E) in 2000, a 26% increase from 1990 levels. The growth seen in Wisconsin exceeded the 15% growth seen across the nation as a whole. Carbon dioxide is the predominant greenhouse gas emitted in Wisconsin, accounting for 83% of total gross emissions in 2000. Methane and nitrous oxide each accounted for 8% of total gross emissions, while hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF<sub>6</sub>) contributed the remaining 1%.

Energy-related activities provide the largest contribution to Wisconsin's greenhouse gas emissions, accounting for 85% of total GHG emissions in 2000. Carbon dioxide emissions from fossil fuel combustion contributed the vast majority of emissions from energy-related activities at 98%. The electric utility sector accounted for 40% of carbon dioxide emissions from fossil fuel combustion in 2000, an increase of 29% since 1990. The majority of the electricity is used by the industrial sector, the largest 'end-use' contributor of emissions. The transportation sector also contributed a significant portion of CO<sub>2</sub> emissions from fossil fuel combustion at 28%. Coal is the primary fuel source for the electric utility sector while petroleum fuels the transportation sector. The agricultural sector was the largest source of both methane and nitrous oxide, with emissions of the former stemming from enteric fermentation and the latter resulting from soil management.

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# 1. INTRODUCTION

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## 1.1. *Background on Climate Change*

The phenomenon of climate change has become a subject of increasing concern to policymakers as scientific evidence regarding its potential negative environmental, social, and economic impacts is building. An international effort is being put forth to understand both the processes involved in the climate system and the extent to which human activities influence these processes. The purpose of this report is to identify and quantify emissions sources in the state of Wisconsin which have the potential to contribute to climate change.

Climate change can result from both natural variability and human activity. Human activity influences climate through the emission of ‘greenhouse gases’ (GHGs) to the atmosphere, thereby affecting the earth’s energy budget. Earth’s energy originates from the sun, and that energy, upon reaching the earth’s surface, is absorbed and then redistributed by atmospheric and oceanic circulations. Eventually, it is radiated back to space. When the amount of incoming energy from the sun is balanced by the amount of outgoing energy from the earth, the earth’s surface temperature remains fairly constant. Greenhouse gases alter climate by absorbing energy as it travels from the earth back to space, in essence acting as a blanket that warms the earth. The greenhouse effect is essential for life on this planet and occurs naturally as a result of gases normally present in the atmosphere. However, an increase in the amount of these gases as a result of anthropogenic activity may exaggerate the greenhouse effect to an extent where undesirable consequences may result. Globally, these consequences may include changes in precipitation patterns, an increase in the frequency and intensity of storms, and an increase in sea level. In Wisconsin, effects including warmer winters and summers, lower lake levels, and a shift in habitat ranges would affect the economy. The potential impacts of global climate change necessitate understanding and preventative action to avoid negative consequences.

Though it has been established that the earth’s climate is changing, as evidenced by an increase in global average surface temperature (IPCC 2001), questions remain as to the extent which human activity is influencing the earth’s climate. The potential impacts of the altered climate are the subject of a great deal of scientific research.

The primary human-influenced gases contributing to the greenhouse effect are carbon dioxide, methane, nitrous oxide, and halogenated substances (HFCs, PFCs, SF<sub>6</sub>). Other trace gases and aerosols also contribute to the greenhouse effect but the magnitude of their contribution is less significant; therefore they are not discussed in this report.

Carbon dioxide is the predominant form of carbon in the atmosphere. Carbon in the atmosphere is cycled between the atmosphere and terrestrial biota (vegetation), and between the atmosphere and ocean water. The global carbon cycle is very complex and involves

numerous geochemical and biological processes. While the carbon cycle is still being studied, scientists have established that the present atmospheric carbon dioxide increase is caused by anthropogenic emissions of the gas, primarily from fossil fuel combustion (IPCC 2001).

Methane is primarily produced through decomposition of organic matter, and is emitted as a result of various agricultural processes as well as during the production/distribution of fuel or incomplete combustion of fossil fuel. More than half of the current contribution of methane to the atmosphere is a result of human activities (IPCC 2001). Though methane is emitted in much smaller amounts than carbon dioxide, it is a more potent greenhouse gas.

Nitrous oxide is a greenhouse gas even more potent than methane. Though emitted in smaller quantities than the other gases, emissions of nitrous oxide from numerous sources, including agricultural soils, fertilizer use, fossil fuel combustion, and waste treatment, are increasing.

By quantifying emissions of the primary greenhouse gases, the DNR can assess both the sources and the magnitude of Wisconsin's contribution to national / global emissions. Such information will facilitate the mitigation of negative impacts from climate change through the reduction of emissions or sequestration of atmospheric carbon.

## **1.2. Study Objectives**

This study quantifies greenhouse gas emissions for the state of Wisconsin during the 1990-2000 time period using the State Inventory Tool (SIT) software developed by the U.S. Environmental Protection Agency (EPA). Such an inventory will facilitate an analysis of trends in emissions levels and sources over time and help to evaluate emission reduction strategies. Updated methodologies based on the guidelines set forth by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) should provide more accurate estimates than those of the past. This work builds on the study conducted by Wisconsin Department of Natural Resources (DNR) which compiles a detailed GHG emissions inventory for the year 1990 (WDNR 1993).

## **1.3. Report Organization**

The focus of this report is greenhouse gas emissions in Wisconsin. Emission quantities are aggregated on a statewide basis. Within the statewide context, emissions in this report are analyzed in the following ways:

**Activity Sector:** Statewide emissions are estimated among major activity sectors including energy, industrial processes, agriculture, land use change and forestry, and waste.

**Economic Sector:** Statewide emissions are distributed among economic sectors including residential, commercial, industrial, transportation, and electric utilities. The emissions from electric utilities can be further distributed among the “end-use sectors” (residential, commercial, industrial, and transportation).

**Gas:** Emissions are quantified for the different greenhouse gases including carbon dioxide, methane, nitrous oxide, and halogenated substances (HFCs, PFCs, SF<sub>6</sub>).

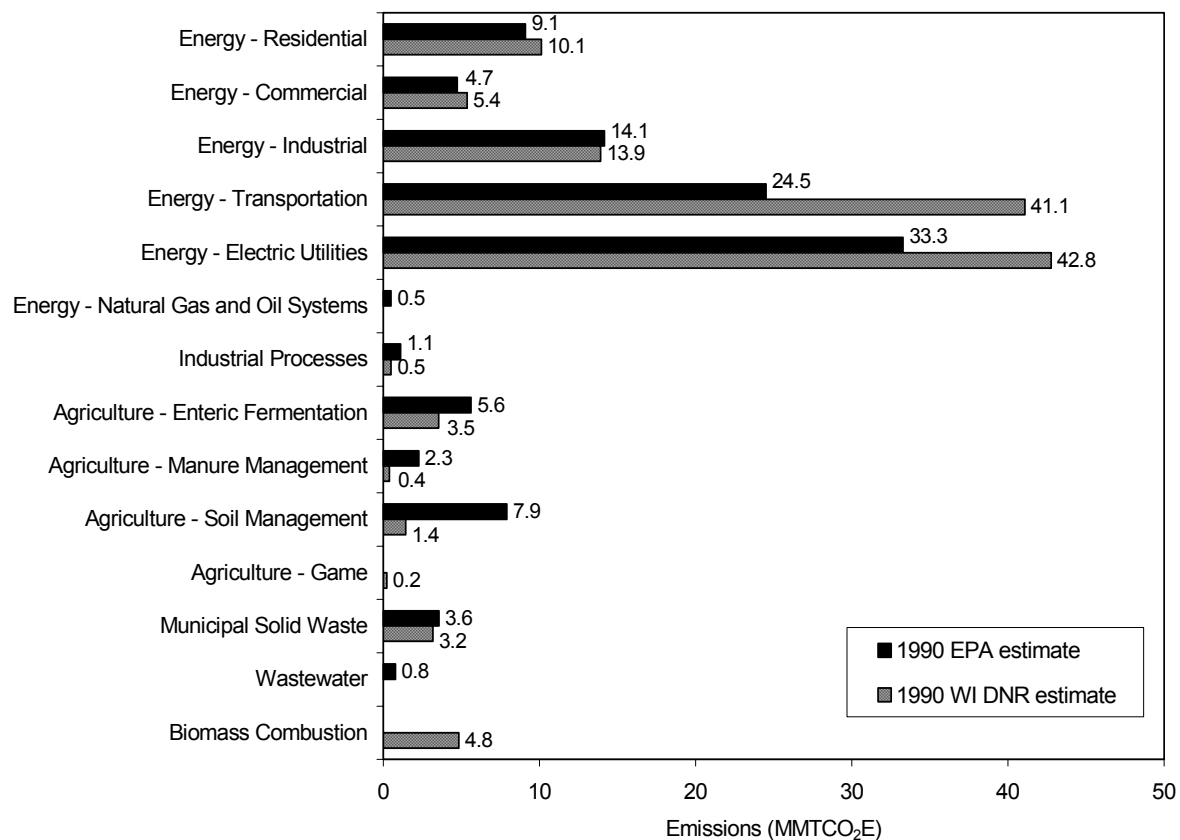
**Time Series:** The report includes emissions estimates for a ten year period starting in 1990 and ending in 2000.

Following this introductory chapter, the main body of the report is contained in the emissions chapter. The emissions chapter includes sections on emissions from each activity sector (energy, industrial processes, agriculture, land-use change and forestry, and waste). Descriptions of the methodologies and data sources used for each activity sector are documented within each section. The final chapter presents and discusses conclusions and recommendations.

#### ***1.4. Changes from the 1990 Emissions Inventory***

The 1990 Greenhouse Gas Emissions Inventory completed by the Wisconsin DNR (1993) reported total greenhouse gas emissions at 128.1 MMTCO<sub>2</sub>E while the EPA State Inventory Tool gives an estimate of 108.3 MMTCO<sub>2</sub>E for 1990, a decrease of 15%. The difference between the two emissions estimates can be traced to the energy and agriculture sectors. A detailed comparison of results attained by the two methods is shown in Figure 1.





**Figure 1. Comparison of EPA State Inventory Tool and Wisconsin DNR Emissions Estimates for 1990**

The Wisconsin DNR used a different approach than the EPA in calculating emissions from the transportation and electric utility sectors, those which account for most of the difference in the estimates. The EPA looks at emissions within a national framework, attributing emissions to each state according to what is produced or consumed within its boundaries. The DNR, on the other hand, looked at all emissions associated with energy use within the state, though the emissions may have been produced elsewhere. For example, the DNR method calculated emissions from electric utilities based on the total megawatt hours required by the system, including those MWh consumed in other states, and also accounted for the emissions created by the production and distribution of the fuel consumed to create electricity. The EPA method looked only at the fuel combusted by the electric utility industry in Wisconsin, leaving the electricity consumed in other states and the fuel production/distribution emissions to be accounted for by other states.

Three specific differences in methodology for computing emissions from transportation explain the difference in estimates. The DNR method included emissions from out-of-state fuel production and distribution as well as vehicle manufacture. These sources accounted for 10.9 MMTCO<sub>2</sub>E, leaving a difference of 5.7 MMTCO<sub>2</sub>E. This remaining difference can be explained by the difference in carbon emissions factors. The DNR used a method based on

emissions factors derived by DeLuchi (1991). There are some problems associated with the use of the DeLuchi emission factors, including the use of different vehicle classifications than those used for the 1990 emissions inventory report, inaccurate fuel efficiencies, no published emissions factor for heavy-duty diesel trucks, the incorporation of all gases into one factor, the inclusion of carbon monoxide emissions, and the use of different global warming potential (GWP) values. On the other hand, the EPA method (for methane) was based on IPCC methodology derived from the EPA's MOBILE5a mobile source emissions model which uses information on ambient temperature, diurnal temperature range, altitude, vehicle speeds, national vehicle registration distributions, gasoline volatility, emission control technologies, fuel composition, and the presence or absence of vehicle inspection/maintenance programs to determine emissions factors. Emissions factors for nitrous oxide were based on tests performed at the National Vehicle and Fuel Emissions Laboratory and additional published studies.

The difference in emissions estimates for electric utilities was primarily due to the inclusion of out-of-state production and distribution of fuel, which accounted for 3.3 MMTCO<sub>2</sub>E, and out-of-state electricity consumption, which accounted for 3.4 MMTCO<sub>2</sub>E. The remaining 2.8 MMTCO<sub>2</sub>E is likely due to the differences in heat rates and emission factors and, amounting to a 7% difference, is within an acceptable range of uncertainty.

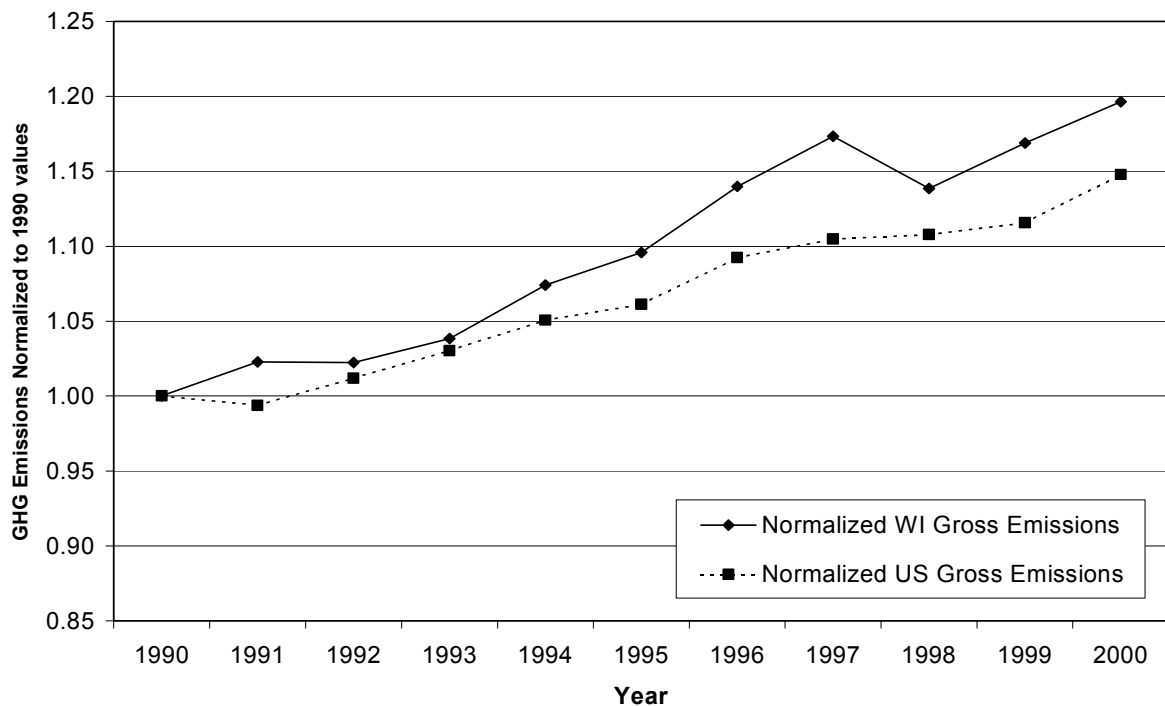
Differences in the agriculture sector were also traced to differences in emission factors as well as the inclusion of additional emission sources not accounted for in the earlier DNR study, including emissions from soils due to application of animal waste, crop residues, nitrogen fixation, histosol cultivation, and volatilization of nitrogen.

To make an equivalent comparison of the past DNR and present EPA estimates of 1990 greenhouse gas emissions, the categories included in one method but not the other were subtracted. After deleting the out-of-state production and distribution of fuel, out-of-state electricity consumption, and vehicle manufacture from the DNR estimate as well as nitrous oxide emissions from manure management and emissions from soils due to application of animal waste, crop residues, nitrogen fixation, histosol cultivation, and volatilization of nitrogen from the EPA estimate, the resulting difference for gross greenhouse gas emissions in 1990 is 4%. Though a quantitative assessment of the uncertainties within the estimates was not performed, a 4% difference is likely within the range of uncertainty. To obtain a more accurate estimate of emissions, it will be necessary to include additional sources of greenhouse gas emissions, obtain more accurate activity data, and improve the accuracy of emission factors. Though further research is needed to improve the accuracy of the current best estimates, the precision of the values calculated on different occasions for the 1990 Wisconsin GHG emissions encourages confidence in the numbers.

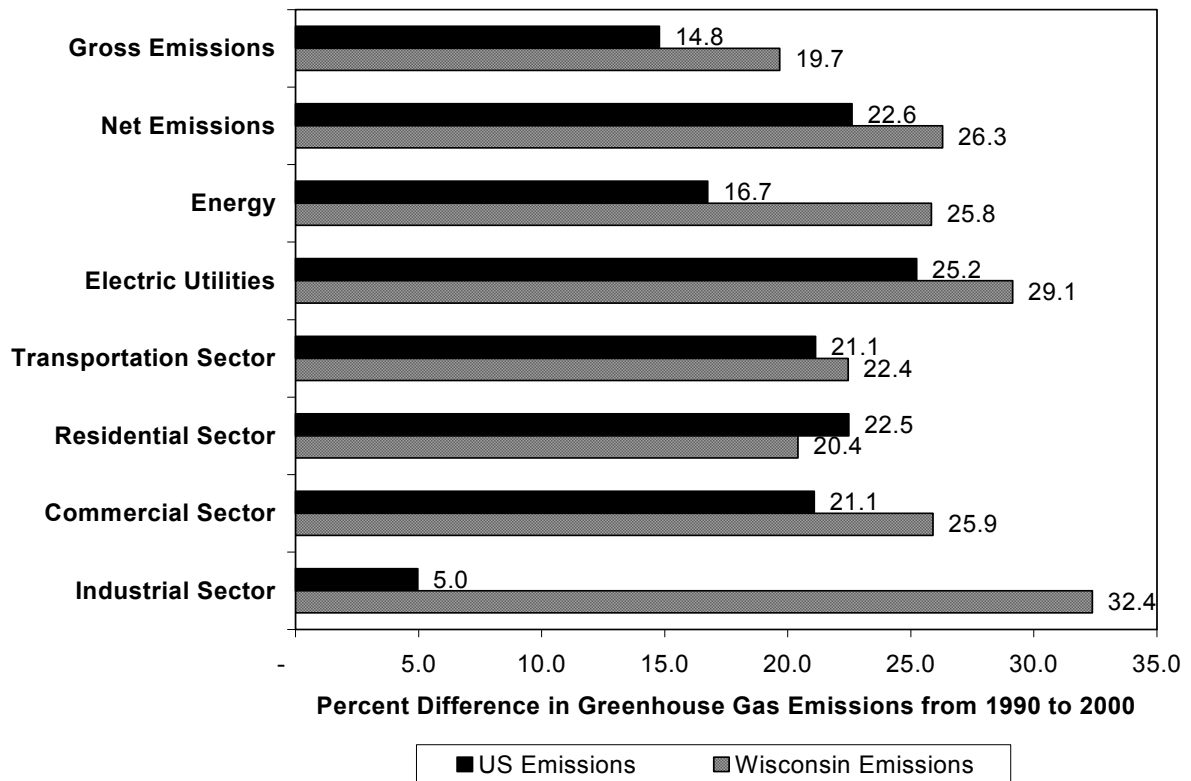
## 1.5. Trends

Wisconsin's greenhouse gas emissions increased between 1990 and 2000. The growth seen in Wisconsin has been more rapid than that seen at the national level (Figure 2). Figure 3 presents the percentage change in emissions seen from 1990 to 2000 across different sectors in Wisconsin and compares them to the growth seen in the United States as a whole, as estimated by USEPA (2001). The values used for the transportation, residential, commercial, and industrial sectors include both the consumption of fuel and the use of electricity.

An analysis of the percent change in emissions from 1990 to 2000 reveals that Wisconsin experienced greater growth in all sectors except residential. The growth in emissions from energy-related activities, primarily fossil fuel combustion, was 9% greater in Wisconsin than across the U.S. Given that the primary fuel sources in Wisconsin are coal and petroleum, both emissions-intensive fuels, the more pronounced growth in emissions from energy-related activities is one reason why growth in emissions in Wisconsin is greater than for the nation as a whole. The greater growth seen in Wisconsin's electric utility and industrial sectors, the primary consumers of coal, is further evidence that economic growth and increased energy demands paired with the use of emissions-intensive fuel sources led to growth in greenhouse gas emissions in Wisconsin which outpaced growth at the national level.



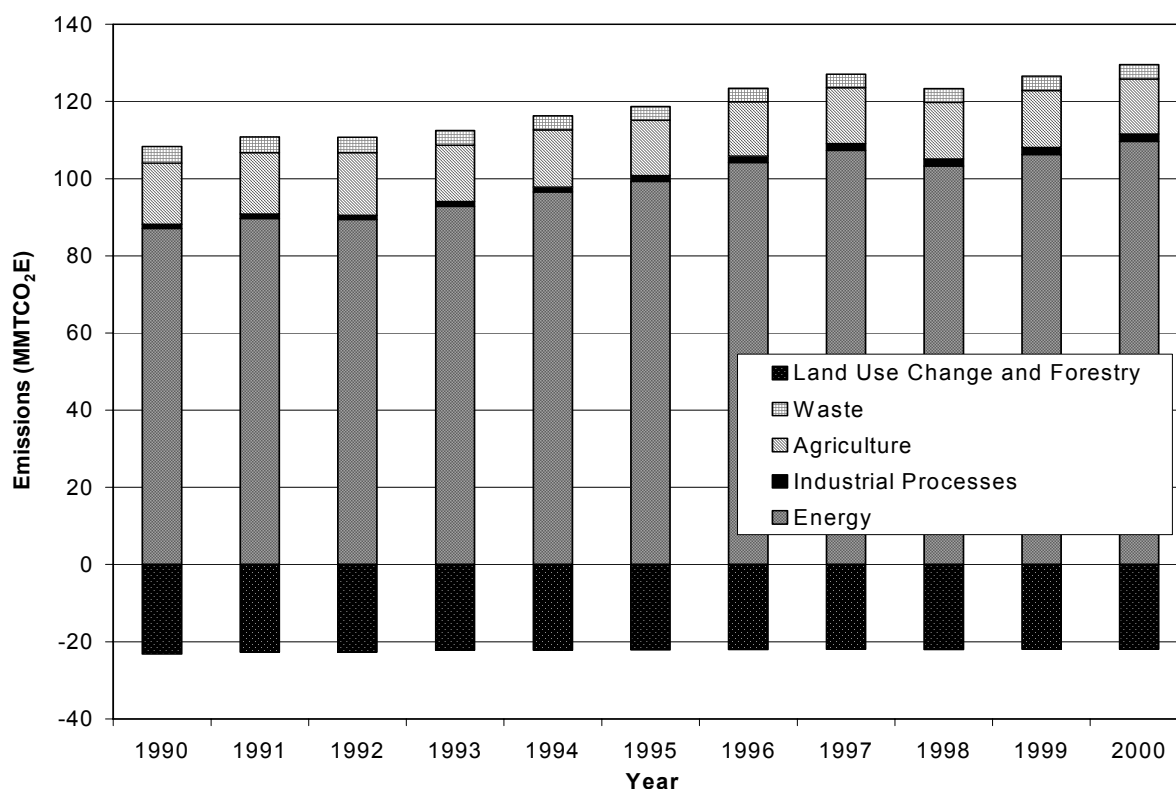
**Figure 2. Relative Gross Greenhouse Gas Emissions from 1990-2000**



**Figure 3. Comparison of the Growth in Greenhouse Gas Emissions between Wisconsin and the United States from 1990 to 2000**

## 2. EMISSIONS

Total gross greenhouse gas emissions in Wisconsin were 129.6 million metric tons of carbon dioxide equivalent (MMTCO<sub>2</sub>E) in 2000. When carbon sequestered in forests is accounted for, net GHG emissions were 17% lower at 107.6 MMTCO<sub>2</sub>E (Figure 4). Wisconsin's emissions account for ~2% of the total U.S. emissions. Greenhouse gas emissions are attributed to five different activity sectors: energy, industrial processes, agriculture, land-use change/forestry, and waste.

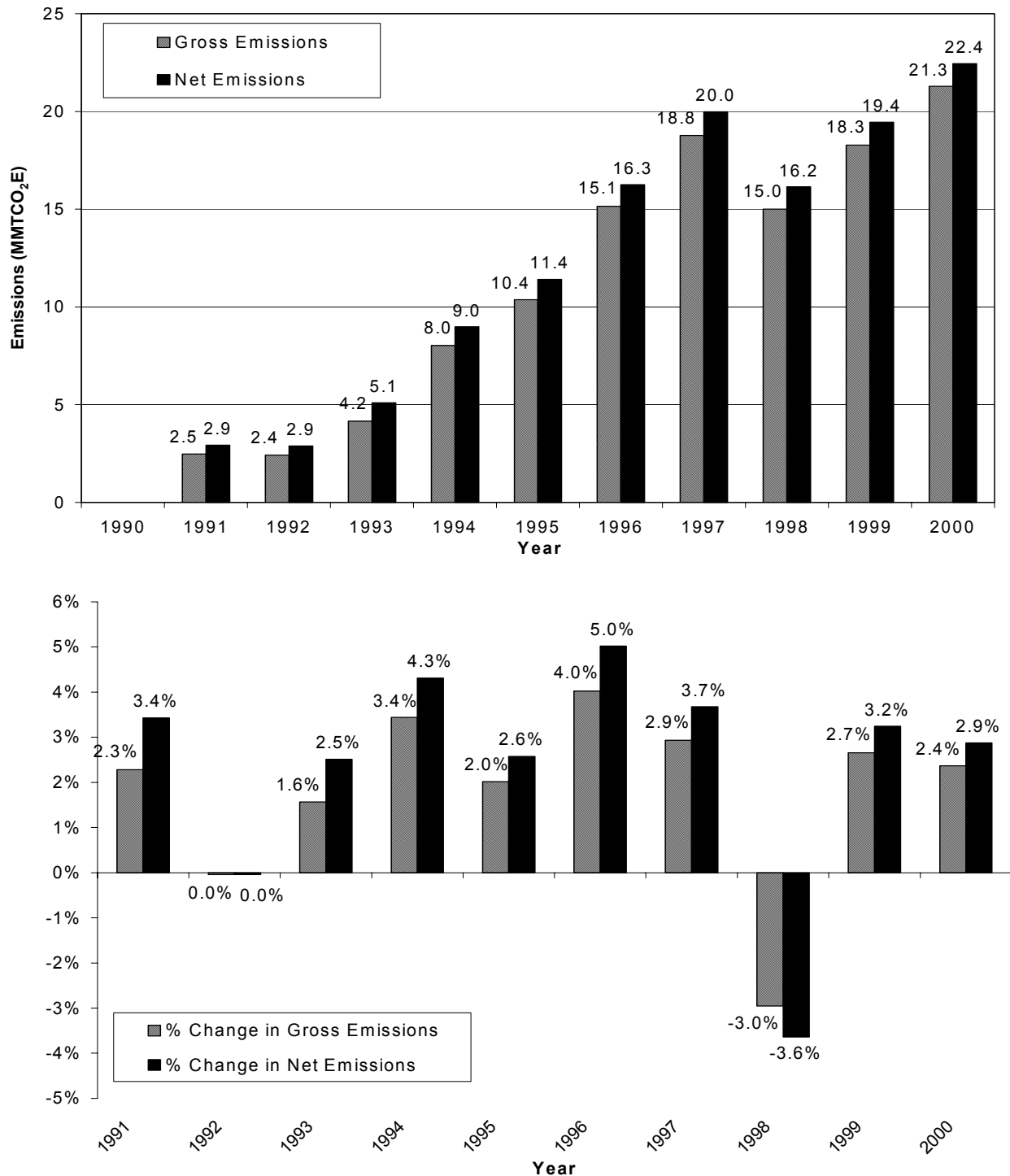


**Figure 4. Wisconsin's Annual Greenhouse Gas Emissions from 1990-2000 by Sector**

Total gross greenhouse gas emissions increased 20% from 1990 to 2000. Figure 5 shows that Wisconsin experienced significant growth in emissions during the 1990s. For each year during that period, there was an increase over the previous year, except from 1991 to 1992 when there was no change in emissions and from 1997 to 1998 when there was a decrease in emissions (Figure 6). This decrease corresponds with an unusually warm winter, which

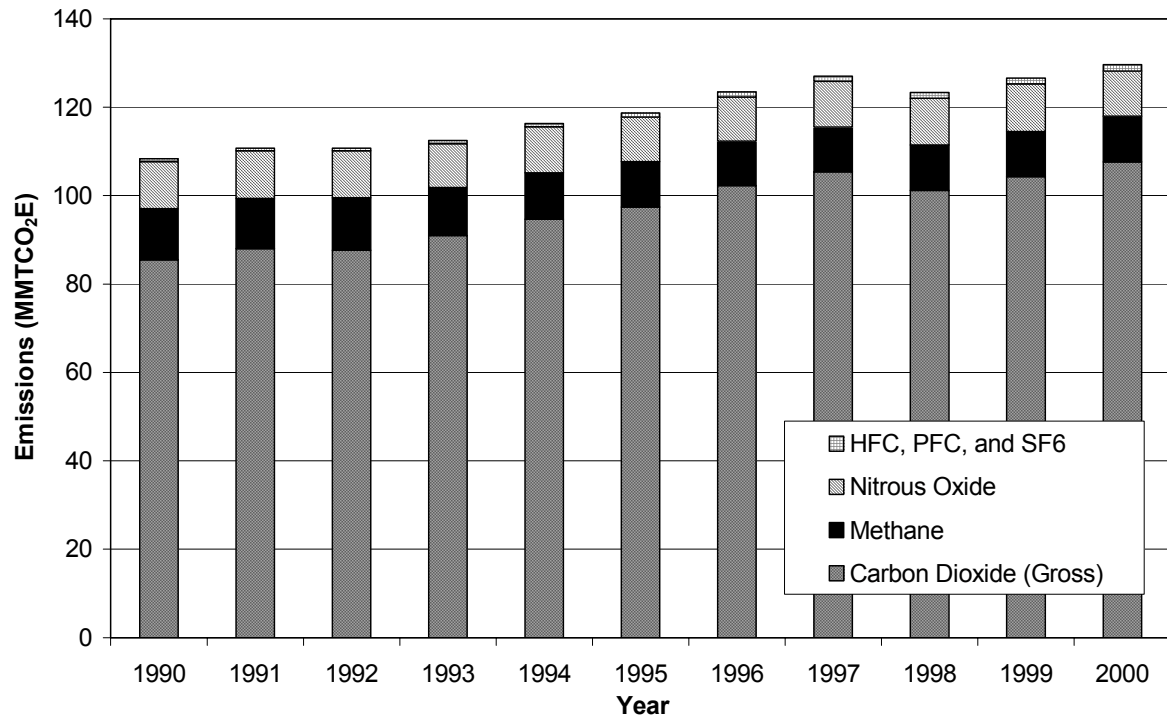
likely decreased the energy needs of Wisconsin residents in 1998. The overall increase in emissions during the 1990s corresponds with a 9.6% increase in Wisconsin's population (U.S. Census Bureau 2000) and a 72% increase in gross state product (USDOD 2003).

**Figure 5. Absolute Change from 1990 in Wisconsin's Annual Greenhouse Gas Emissions**



**Figure 6. Annual Percent Change in Wisconsin's Annual Greenhouse Gas Emissions**

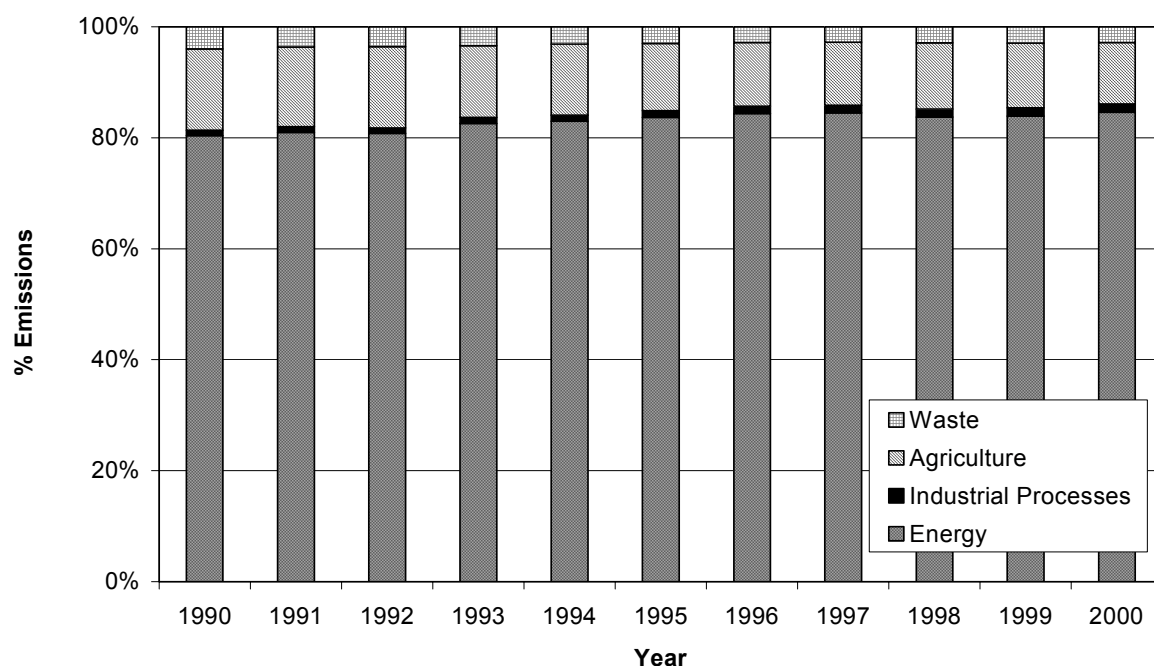
Carbon dioxide is the predominant greenhouse gas emitted in Wisconsin. In 1990, 79% of emissions were carbon dioxide and that percentage increased to 83% in 2000. This growth corresponds with the increase in fossil fuel consumption during the study period.



**Figure 7. Wisconsin's Annual Greenhouse Gas Emissions from 1990-2000 by Gas**

## **2.1. Energy**

Energy-related activities provide the largest contribution to Wisconsin's greenhouse gas emissions, accounting for 85% of total GHG emissions in 2000 (Figure 8). The percentage of total GHG emissions coming from energy-related activities has increased 5% since 1990.



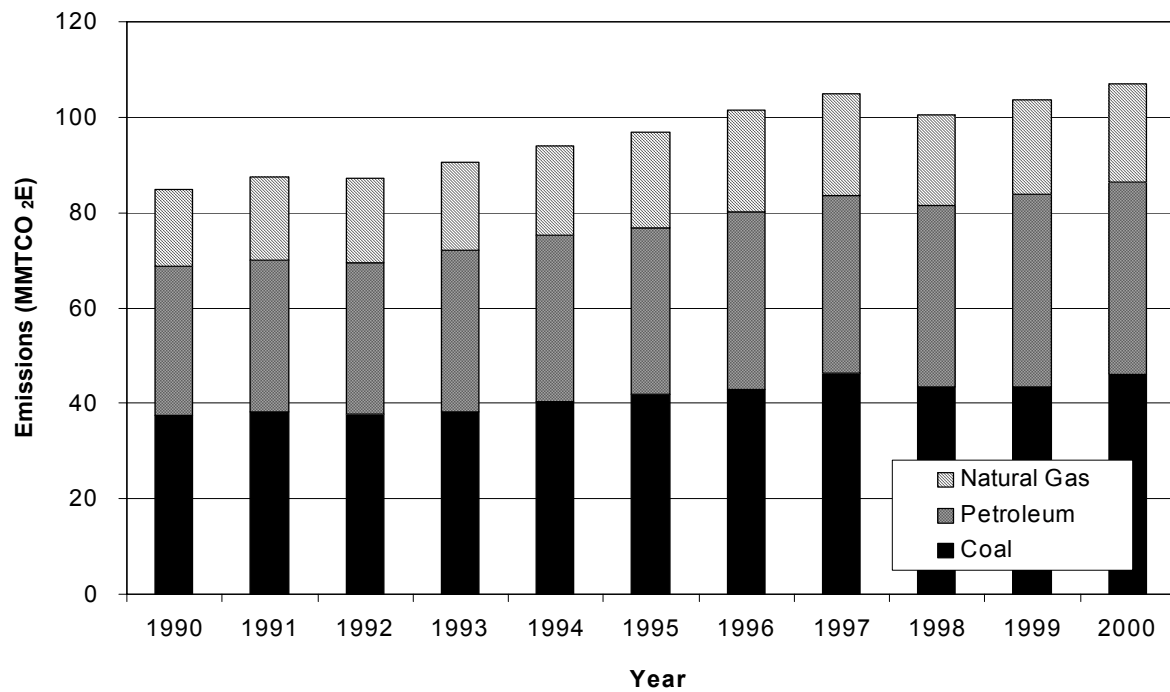
**Figure 8. Relative Contribution by Sector to Wisconsin's Annual Greenhouse Gas Emissions**

The four categories of energy-related activities discussed in this report are: carbon dioxide emissions from fossil fuel combustion, methane and nitrous oxide emissions from stationary source fossil fuel combustion, methane and nitrous oxide emissions from mobile source fossil fuel combustion, and methane emissions from natural gas and oil systems. Of these categories, carbon dioxide emissions from fossil fuel combustion is the largest source at 98% of the total emissions from energy-related activities. This percentage has remained constant from 1990-2000.

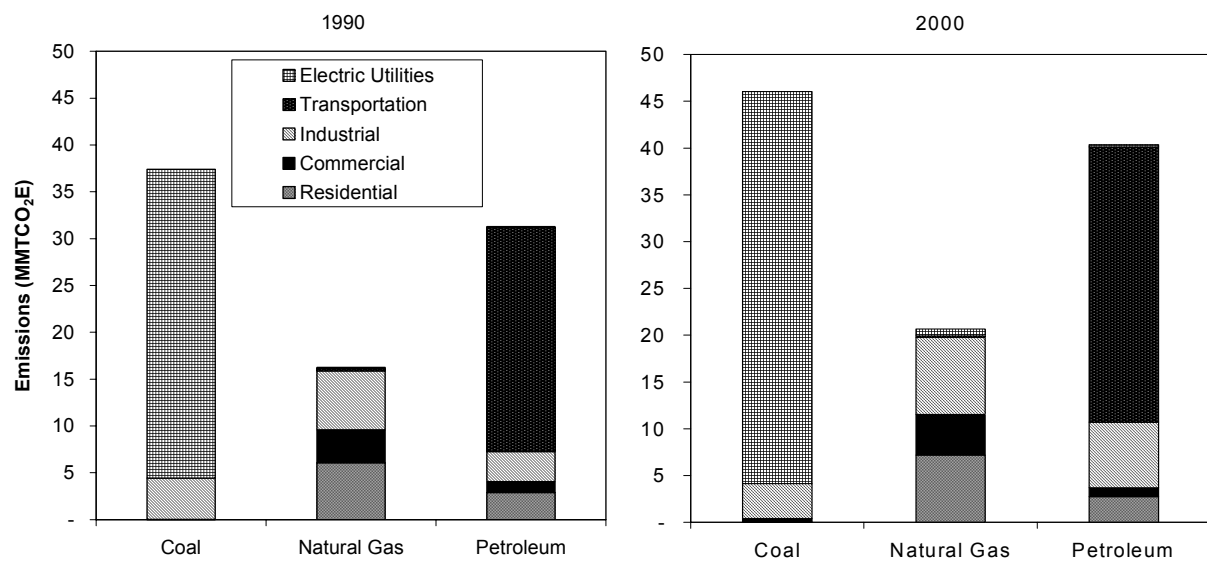
### **2.1.1. Carbon Dioxide Emissions from Fossil Fuel Combustion**

Energy-related activities contribute to greenhouse gas emissions primarily through the burning of fossil fuels such as coal, petroleum, and natural gas. Energy from fossil fuel combustion is used to heat residential and commercial buildings, generate electricity, produce steam for industrial processes, and power motor vehicles. Fossil fuels emit carbon dioxide ( $\text{CO}_2$ ) as the carbon in the fuel is oxidized during combustion. Precursors of  $\text{CO}_2$ , such as carbon monoxide, are emitted as by-products of incomplete combustion but are eventually oxidized to  $\text{CO}_2$ . Emissions from fossil fuel combustion are mainly comprised of carbon dioxide but also contain some methane and nitrous oxide as will be discussed in the following sections. Coal, which is used primarily for generating electricity, is the largest fuel source in Wisconsin followed by petroleum and natural gas (Figure 9). The amount of coal used for electricity generation increased by 27% from 1990 to 2000. The use of petroleum in the transportation sector has also increased significantly (23%) over the same period (Figure 10).



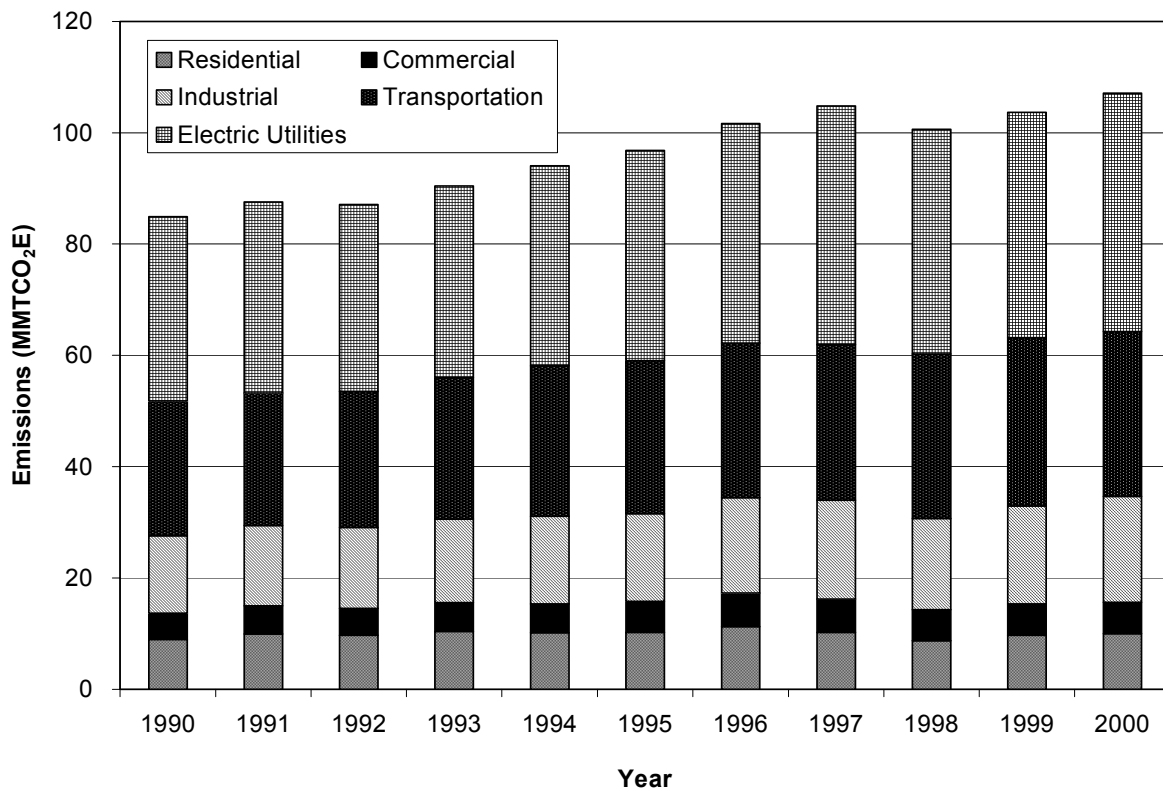


**Figure 9. Wisconsin's Annual Carbon Dioxide Emissions from Fossil Fuel Combustion by Fuel Type**



**Figure 10. Distribution of CO<sub>2</sub> Emissions by Fuel Type and Economic Sector for 1990 and 2000**

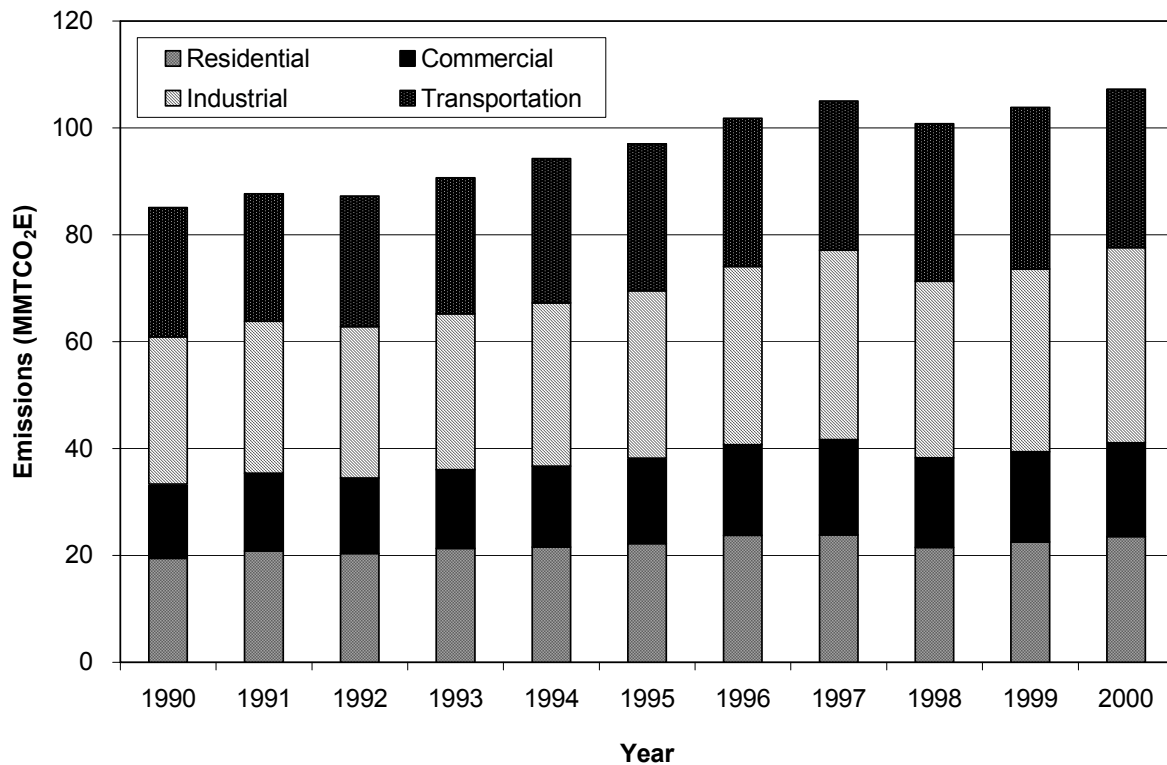
Emissions of carbon dioxide from fossil fuel combustion increased in each economic sector during the 1990-2000 time period (Figure 11). The greatest absolute growth occurred in the electric utility sector where emissions increased by 10 MMTCO<sub>2</sub>E during the time period, a 29% increase. The industrial sector experienced a 36% increase in emissions relative to 1990 levels, though the absolute growth was 5 MMTCO<sub>2</sub>E. The transportation sector also saw a growth in emissions of 5 MMTCO<sub>2</sub>E, a 22% increase from 1990 to 2000. Growth in absolute emissions from the residential and commercial sectors was significantly less, an increase of 11% and 20% respectively. The electric utility sector contributed 40% of the total carbon dioxide emissions from fossil fuels in 2000, more than was contributed by any other sector. The transportation sector was the next largest contributor, emitting 28% of total carbon dioxide emissions from fossil fuel, followed by the industrial sector at 18%. The residential and commercial sectors contributed 9% and 5% respectively.



**Figure 11. Wisconsin's Annual Carbon Dioxide Emissions from Fossil Fuel Combustion by Economic Sector**

When emissions from the electric utilities are distributed among the respective end-use sectors, the industrial sector emerges as the largest emitter of carbon dioxide, contributing 33% of total CO<sub>2</sub> emissions from fossil fuels, as well as the largest consumer of electricity (Figure 12). The transportation sector is again the second largest contributor to emissions at 28%, followed by the residential sector at 23% and the commercial sector at 16%. The

residential and commercial sectors are estimated to use 31% and 28%, respectively, of the electricity generated in Wisconsin.



**Figure 12. Wisconsin's Annual Carbon Dioxide Emissions from Fossil Fuel Combustion by End-Use Sector**

## METHODOLOGY

Carbon dioxide emissions from combustion of fossil fuels were estimated using the State Inventory Tool (SIT) developed for the State and Local Climate Change Program, U.S. Environmental Protection Agency and Emissions Inventory Improvement Program by ICF Consulting. The methods used in the SIT and described in the guidance document (EIIP 2003) were taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and are in accordance with IPCC's *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). These methods are also used for the U.S greenhouse gas inventory (USEPA 2003).

The amount of CO<sub>2</sub> emitted from fossil fuel depends on the type and amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel that is oxidized. Coal contains the highest amount of carbon per unit of energy while petroleum contains about

75% and natural gas 55% that of coal. Not all carbon in fuel products is oxidized to CO<sub>2</sub>, as inefficient combustion leaves a small fraction unburned, and fossil fuels may also be used for non-energy purposes. Under the IPCC guidelines, carbon dioxide emissions from biomass fuels grown in a sustainable manner are not counted because the carbon dioxide emitted from the combustion of biomass will be taken up by the growing vegetation that replaces what was harvested. In the United States, biomass fuels are generally grown on a sustainable basis so combustion of biomass fuels is not included in emissions estimates.

The estimation methodology consists of seven steps:

- (1) Obtain required energy data including fossil fuel energy consumption by fuel type and sector, carbon (C) content coefficients, amount of carbon sequestered in products, and percentage of carbon oxidized during combustion.
- (2) Estimate total carbon content in fuels; To estimate the total carbon content of a particular fuel, multiply the Btus consumed by its carbon content coefficient

$$\text{Total Carbon Contained in Fuel } i \text{ (lbs C)} = \text{Fuel Consumption for Fuel } i \text{ (BBtu)} \times \text{C Content Coefficient for Fuel } i \text{ (lbs C/MMBtu)}$$

In general, carbon content coefficients are determined based on the composition and heat contents of fuel samples. Based on these scientific studies and detailed fuel data, the Energy Information Administration (EIA) estimates carbon content coefficients for a wide range of fuel types. For each fuel type, divide the results by 2000 lbs per ton to obtain tons of carbon. For each sector, sum the results of the fuel types to obtain the total carbon content in tons.

- (3) Estimate the amount of carbon stored in non-energy products for a significant period of time using empirically determined storage factors developed by the EPA for various fuels. The storage factor is equal to the ratio of carbon stored in the final products to total carbon content for the non-energy fossil fuel feedstocks used in industrial products.

$$\text{Carbon Stored (lbs C)} = \text{Non-energy use of fuel (MMBtu)} \times \text{C Content Coefficient (lbs C/MMBtu)} \times \text{Storage Factor (\%)}$$

- (4) Calculate net potential carbon emissions. Subtract the carbon stored (as calculated in Step 3) from the total carbon estimated for each fuel type (from Step 2).
- (5) Estimate the amount of carbon oxidized during combustion. Not all carbon is oxidized during the combustion of fossil fuels. For natural gas and LPG, less than 0.5 percent of the carbon is unoxidized during combustion and remains as soot or ash in the burner, stack, or in the environment. This is equivalent to a fraction oxidized of 0.995. For coal and petroleum fuels, approximately 1 percent is not oxidized and forms soot or ash. Thus the fraction oxidized is 0.99. These values vary based on fuel quality and type of combustion technology (particularly for coal). To complete this step, multiply net carbon

content for each fuel and sector in tons (Step 4) by the fraction of carbon oxidized to obtain the total amount of carbon emitted to the atmosphere.

- (6) Convert units to million metric tons of carbon equivalent. First, multiply the total carbon oxidized in tons (Step 5) for each fuel type and sector by the ratio of metric tons per ton (0.9072) to obtain metric tons of carbon equivalent emissions. Then, sum across each fuel type and sector to find total state emissions of CO<sub>2</sub> from energy consumption (again, measured in metric tons of carbon). Divide by 10<sup>6</sup> to express emissions in million metric tons of carbon equivalent (MMTCE). To convert MMTCE to MMTCO<sub>2</sub>E, simply multiply by 44/12, the ratio of the molecular weight of carbon dioxide to carbon. Units such as carbon equivalents and carbon dioxide equivalents are useful for comparing emissions of different greenhouse gases based on their global warming potential (GWP). The global warming potential of a greenhouse gas is an indication of its ability to trap heat in the atmosphere relative to carbon dioxide. In general, the formula to derive carbon equivalents is:  $MMTCE = (\text{million metric tons of a gas}) * (\text{GWP of the gas}) * (12/44)$ .

To distribute electric utility emissions to end-use sectors, it is necessary to obtain electricity consumption data by each of the four end-use sectors (residential, commercial, industrial, and transportation) in the state. Default values for the percentage of electricity used by each sector may be obtained from the *State Energy Data Report* (EIA 2001a). Using these figures, states can calculate the fraction of total electricity that is consumed by each of the four end-use sectors. Each of these fractions is multiplied by total emissions from the electric utility sector, giving the portion of electric utility emissions attributable to each end-use sector. The end-use emissions from electricity consumption are then added to the other sectoral emissions.

## DATA SOURCES

The State Inventory Tool includes default state-level energy use statistics for Wisconsin from the *State Energy Data Report (SEDR)* (EIA 2001a) published by the Energy Information Administration. The data are based on primary fuel type (coal, natural gas, and petroleum) and secondary fuel type (e.g. type of petroleum categorized by economic sector). The default carbon content coefficients used in the SIT were also obtained from the Energy Information Administration (EIA) as were data on the non-energy use of fuel and carbon storage factors.

The Wisconsin Department of Administration also publishes state-level energy use statistics (WDOA 2002). Emissions were calculated with the SIT using data from both the WDOA and EIA, and the results were found to be very similar. Though small differences were seen in estimates of carbon dioxide emissions from the industrial sector resulting from coal and petroleum combustion, estimates of total emissions from the industrial sector were very close. Therefore, the default EIA data were used because the EIA data provided more detailed information, was used consistently throughout the SIT, and was the most efficient option.

### 2.1.2. Methane and Nitrous Oxide Emissions from Stationary Source Fossil Fuel Combustion

Stationary sources are those from all economic sectors except transportation. Fossil fuel combustion results in emissions of gases besides carbon dioxide, including methane ( $\text{CH}_4$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ). Emissions of these gases from stationary combustion sources depend on fuel and source characteristics, combustion technology, pollution control equipment, and ambient environmental conditions. Nitrous oxide emissions from stationary combustion are closely related to air-fuel mixes and combustion temperatures, as well as the characteristics of any pollution control equipment. Methane emissions from stationary combustion are primarily a function of the  $\text{CH}_4$  content of the fuel and the combustion efficiency. Wood is included as a fuel source in this section because the methane and nitrous oxide emissions resulting from wood consumption are not sequestered in young forests.

Stationary combustion sources in Wisconsin emitted 0.17 MMTCO<sub>2</sub>E of methane and 0.37 MMTCO<sub>2</sub>E of nitrous oxide in 2000. Compared to the 77.42 MMTCO<sub>2</sub>E of carbon dioxide emitted by stationary sources in 2000, the amounts of methane and nitrous oxide emissions from stationary sources are very small. During the 1990-2000 time period, emissions of methane from stationary sources decreased due to the reduction in wood combustion in the residential sector (Figure 13). Despite the decrease, wood remains the largest contributor to methane emissions from stationary sources among the fuel types. Nitrous oxide emissions increased over the same time period due to increased coal combustion in the electric utility sector, as shown in Figure 13.

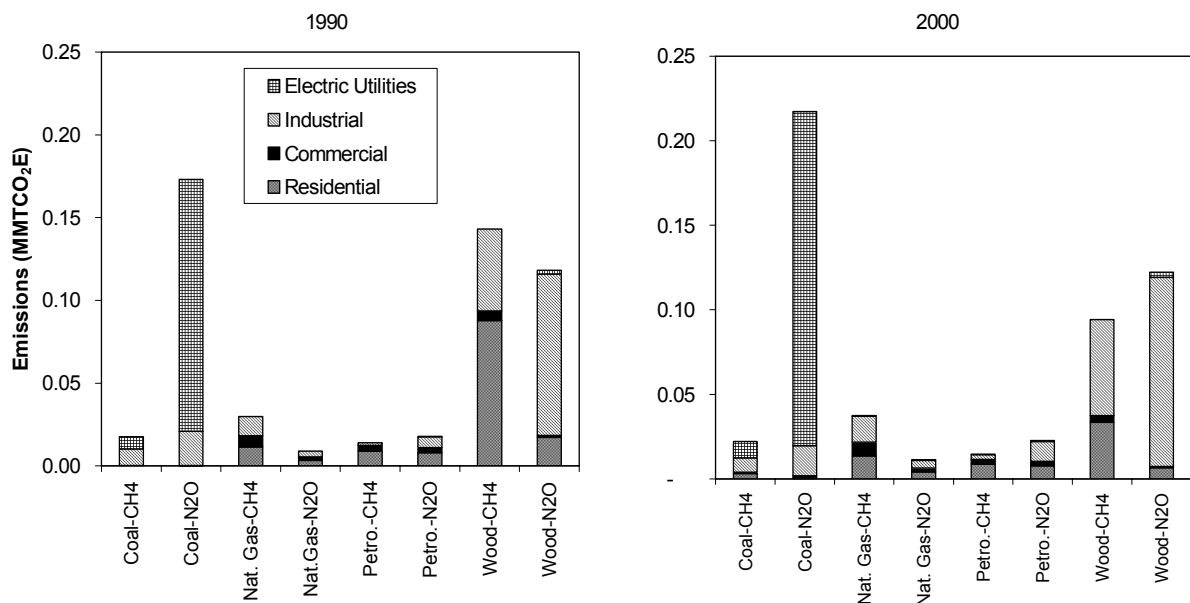


Figure 13. Distribution of Emissions by Fuel Type and Economic Sector for 1990 and 2000

## METHODOLOGY

The State Inventory Tool follows the Tier 1 method in the IPCC guidelines (IPCC/UNEP/OECD/IEA 1997) for estimating methane and N<sub>2</sub>O emissions from stationary combustion. This method is described in detail in the Emission Inventory Improvement Program guidance document (EIIP 2003).

Emissions of CH<sub>4</sub> and N<sub>2</sub>O were estimated from four primary fuel types—coal, oil, natural gas, and wood. The consumption data for each fuel type were grouped by economic sector and then multiplied by IPCC emission factors specific to each fuel type and sector (IPCC/UNEP/OECD/IEA 1997). The methodology consists of five steps:

- (1) Obtain data on the amount of coal, petroleum, natural gas, and wood combusted in the residential, commercial, industrial, and electric utility sectors.
- (2) Make data adjustments by subtracting the quantity of fuel consumed in non-energy uses where appropriate.
- (3) Estimate emissions using the IPCC Tier 1 approach by multiplying fuel use in BBtu by the appropriate emission factor.
- (4) Sum the estimates of CH<sub>4</sub> and N<sub>2</sub>O emissions across all fuel types and sectors to derive total emissions (in metric tons) of each gas.
- (5) To obtain emissions in metric tons of CO<sub>2</sub> equivalent (MTCO<sub>2</sub>E), multiply the emissions in metric tons for each of the gases by the Global Warming Potential (GWP) for each gas. The GWPs of CH<sub>4</sub> and N<sub>2</sub>O are 21 and 310, respectively.

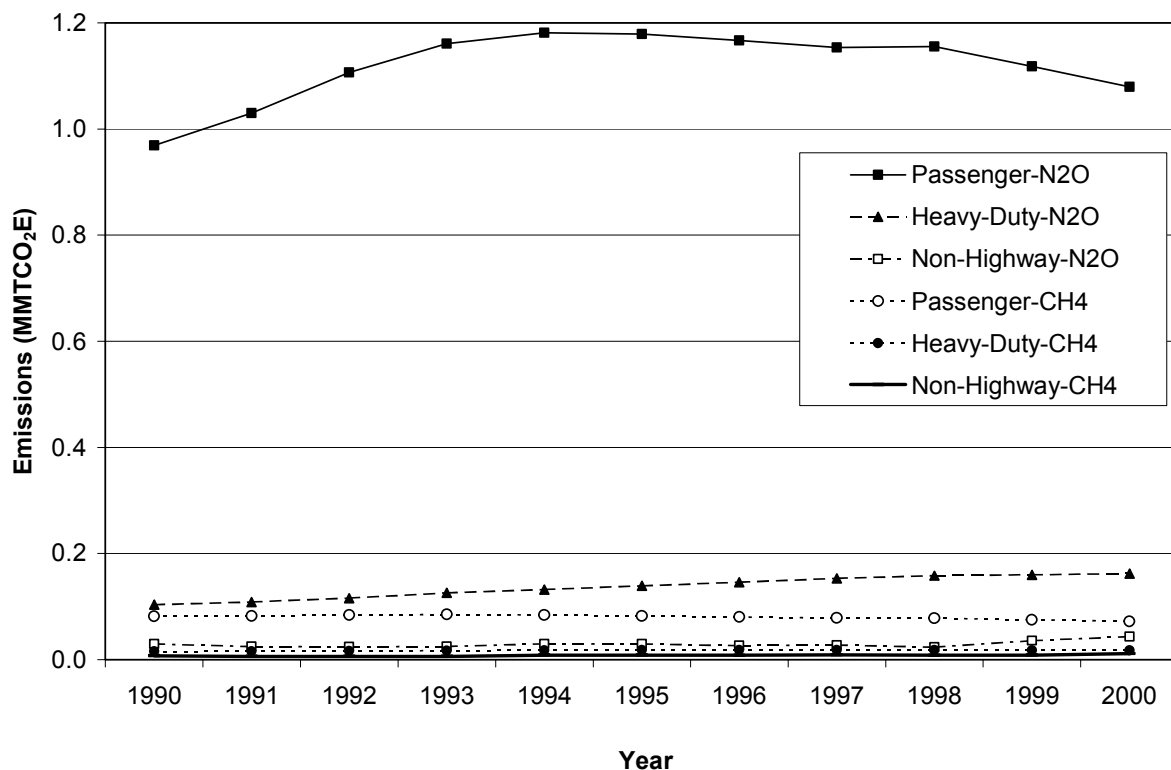
## DATA SOURCES

The fuel consumption data for estimates of methane and nitrous oxide emissions from stationary combustion were obtained from the State Energy Data Report (SEDR) (EIA 2001a) published by the Energy Information Administration in the Department of Energy, the same source as used for estimates of carbon dioxide from fossil fuel combustion.

### **2.1.3. Methane and Nitrous Oxide Emissions from Mobile Source Fossil Fuel Combustion**

Mobile sources emit methane and nitrous oxide to the atmosphere, in addition to carbon dioxide. Methane and nitrous oxide emissions are determined by air-fuel mixes, combustion, temperatures, fuel characteristics, and the use of pollution control equipment. For example, N<sub>2</sub>O emissions are largely dependent on the catalytic processes used to control other emissions. Methane emissions are determined not only by the methane content of the fuel, but also by the amount of uncombusted hydrocarbons passing through the engine, and the presence of pollution control technologies such as catalytic converters (USEPA 2003).

Emissions from mobile combustion were estimated by fuel type (e.g. motor gasoline, diesel fuel, jet fuel), vehicle type (e.g. passenger cars, light-duty trucks), and transport mode (e.g., highway, air, rail). Mobile sources emitted 0.09 MMCO<sub>2</sub>E of methane and 1.2 MMCO<sub>2</sub>E of nitrous oxide in 2000 in Wisconsin. The largest source of emissions within the transportation sector was passenger vehicles for both nitrous oxide and methane (Figure 14). Emissions of both gases increased between 1990 and 1995, then began to decrease. This trend is likely due to the introduction of emission control technologies in 1994 which reduced emissions of both methane and nitrous oxide (USEPA 2003). Diesel fuel was a smaller source of emissions than gasoline, though emissions from diesel-powered vehicles are increasing. Emissions from non-highway transportation modes such as airplanes and trains were very small.



**Figure 14. Trends in Methane and Nitrous Oxide Emissions from Mobile Source Fossil Fuel Combustion by Gas and Vehicle Type from 1990-2000**

## METHODOLOGY

The estimation of methane and nitrous oxide emissions from mobile source fossil fuel combustion is a complex process. The methodology used in the State Inventory Tool is described in detail in the guidance document (EIIP 2003). The preferred method is taken from the Intergovernmental Panel on Climate Change (IPCC) report entitled *IPCC*



*Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and is also used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (USEPA 2003). The SIT guidance builds on the IPCC methodology by also providing guidance on how to obtain activity data necessary to calculate emissions (e.g., vehicle miles traveled).

Estimates of CH<sub>4</sub> and N<sub>2</sub>O emissions were obtained by applying emission factors to activity data for each category. For highway vehicles, these data include annual vehicle miles traveled (VMT), age distribution, vehicle mileage accumulation, and pollution control technology type for each vehicle type. For aviation, data on energy consumption of jet fuel and aviation gasoline were used.

The following steps are required to estimate motor vehicle emissions of CH<sub>4</sub> and N<sub>2</sub>O:

- (1) Obtain activity data on vehicle miles traveled per road type. The default data from the Federal Highway Administration, which are included in the State Inventory Tool, were used for estimates presented in this report.
- (2) Calculate the vehicle miles traveled for each vehicle type by multiplying the total VMT for each road type by the national percentage of that mileage accounted for by each vehicle type, then sum the VMT for all road types.
- (3) Convert the vehicle miles traveled data for use with existing emission factors. The Federal Highway Administration defines vehicle types slightly differently than the EPA, thus the VMT data must be distributed according to the EPA system.
- (4) Distribute vehicle miles traveled by vehicle age to account for changes over time in emission control technologies. VMT must be apportioned by both the vehicle age distribution and by the annual age-specific vehicle mileage accumulation. The State Inventory Tool uses the United States averages for both distributions obtained from the US EPA (2002). To incorporate both the vehicle age distribution and the annual age-specific vehicle mileage accumulation, the distribution tables are cross-multiplied and the resulting distribution is applied to the total VMT for each vehicle type.
- (5) Determine emissions control systems for each vehicle type, as specified by EPA, and allocate the VMT to the relevant emission control technologies.
- (6) Estimate emissions for each vehicle type by multiplying VMT by the appropriate emission factors.
- (7) Calculate total emissions in metric tons of carbon dioxide equivalent (MTCO<sub>2</sub>E) by summing across all vehicle and emission control types, converting from grams to metric tons, and multiplying by the appropriate Global Warming Potential.

Emissions from non-highway vehicles are calculated using a different method. Data (in Btus) were obtained on the state's fuel consumption by each type of non-highway vehicle.

Values in Btus are converted to kilograms then multiplied by the appropriate emission factors to determine grams of CH<sub>4</sub> and N<sub>2</sub>O, which are then converted to metric tons.

## **DATA SOURCES**

Default data on highway vehicles used in the State Inventory Tool were obtained from both the Federal Highway Administration (FHWA) and the Energy Information Administration (EIA). VMT values were found in the FHWA's *Highway Statistics* report, which provides annual estimates of VMT based on traffic count data. These estimates are available on the Internet at <http://www.fhwa.dot.gov/ohim/ohimstat.htm>, in the table entitled "Vehicle miles of travel, by functional system (Table VM-2)." This table shows the number of miles of travel for each road type in each state (FHWA 2000). The *Highway Statistics* report also provided national VMT by vehicle type for each road type (FHWA 2000).

Data on aviation fuel use were obtained from the Energy Information Administration (EIA 2001a) and were provided as default data in the SIT. Data on distillate and residual fuel oil use by boats and vessels were obtained from the National Energy Information Center (Hernandez 2003), and data on gasoline use by boats and vessels were obtained from the Federal Highway Administration (FHWA 2000). Data on locomotive fuel use were obtained from the tables published by the Energy Information Administration on fuel oil and kerosene use (EIA 2001b). Data on diesel fuel use by farm equipment came from the same source. Construction and non-highway vehicle fuel use also came from the EIA (EIA 2001a).

### **2.1.4. Methane Emissions from Natural Gas and Oil Systems**

Natural gas and oil systems are comprised of the following stages: oil and gas production, crude oil transportation and refining, and natural gas processing, transmission/storage, and distribution. Methane is emitted during oil and gas production, storage, transportation, and distribution. Emissions from these systems stem from normal operations (engine/turbine exhaust or venting/flaring), routine maintenance, and system upsets. In the production stage, oil and gas are withdrawn from underground sources. Leaks or venting from gathering systems result in methane emissions. This aspect of the system is not addressed in this report as there is no oil or gas production in Wisconsin. The next stage in oil systems is transportation and refining. Here, venting from crude oil storage facilities is the largest source. Wisconsin has only one small oil refinery so emissions from oil systems are negligible. Natural gas systems proceed to processing, transport, and distribution. The processing stage removes water, recovers heavier hydrocarbons, and prepares dried gas for transportation through pipelines. Gas is transmitted through high-pressure pipelines which involve metering stations, maintenance facilities, and compressor stations. Emissions can result from leaks, fugitive sources, exhaust, and vents. Gas is transported to local distribution companies which consist of networks of low-pressure pipelines. Emissions at this stage result from leaks, meters, regulators, and accidents.

Emissions from natural gas and oil systems in Wisconsin come from the transmission and distribution of natural gas. In 2000, emissions from these sources totaled 0.7 MMTCO<sub>2</sub>E, a 48% increase from 1990 levels. The growth in emissions is due to an increase in the mileage of transmission and distribution pipeline in the state. Overall, natural gas systems make a small contribution to total greenhouse gas emissions in Wisconsin, but are an important source of methane nonetheless.

## **METHODOLOGY**

The methodology presented in the State Inventory Tool guidance document (EIIP 2003) is based on the “Tier 3” approach developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997), however, the method is simplified for purposes of state-level estimation. This approach incorporates emission factors which represent emissions both from a specific activity and from several associated activities. Emission factors were developed from a study conducted by the Gas Research Institute and the U.S. Environmental Protection Agency (GRI 1996) based on a large survey of emissions from the natural gas industry. The simplified approach used in the SIT is relatively accurate. However, at the state-level there is potential for an overestimation of emissions if a state transmits large amounts of gas but does not produce much gas (as is the case in Wisconsin) because the method would allocate to the state some emissions from other states’ gas production.

The following steps are required to estimate emissions from natural gas systems in Wisconsin:

- 1) Obtain required data including number of miles of transmission pipeline, number of transmission compressor and storage compressor stations (or use a default based on pipeline length), number of miles of distribution pipeline, and number of services (customer connections).
- 2) Calculate CH<sub>4</sub> emissions by multiplying activity data by the appropriate emission factor.
- 3) Convert units to metric tons of carbon dioxide equivalent by multiplying by the global warming potential of methane.

## **DATA SOURCES**

Data on the number of miles of transmission and distribution pipeline as well as the number of services were obtained from the *Gas Facts* publication put out by the Department of Transportation’s Office of Pipeline Safety (OPS) (OPS 2001). The number of compressor stations was estimated based on a default number of stations per mile of pipeline provided in the SIT.

## 2.2. Industrial Processes

Greenhouse gases are produced as a by-product of various industrial processes. These activities are not related to energy consumption and include processes such as chemical transformation. Only those processes found in the industrial sector of Wisconsin which result in significant GHG emissions are addressed in this report. They include lime manufacture, limestone and dolomite use, consumption of ozone-depleting substitutes (ODS), semiconductor manufacture, and electric power transmission and distribution. Industrial processes in Wisconsin emit carbon dioxide and man-made fluorinated gases. The total amount of greenhouse gases emitted from industrial processes in 2000 was 1.9 MMTCO<sub>2</sub>E. This is a relatively small contribution to the total greenhouse gas emissions in Wisconsin. However, emissions from industrial processes have increased 77% since 1990 (Figure 15). This great increase in emissions was driven by the increase in the consumption of ozone-depleting substitutes.

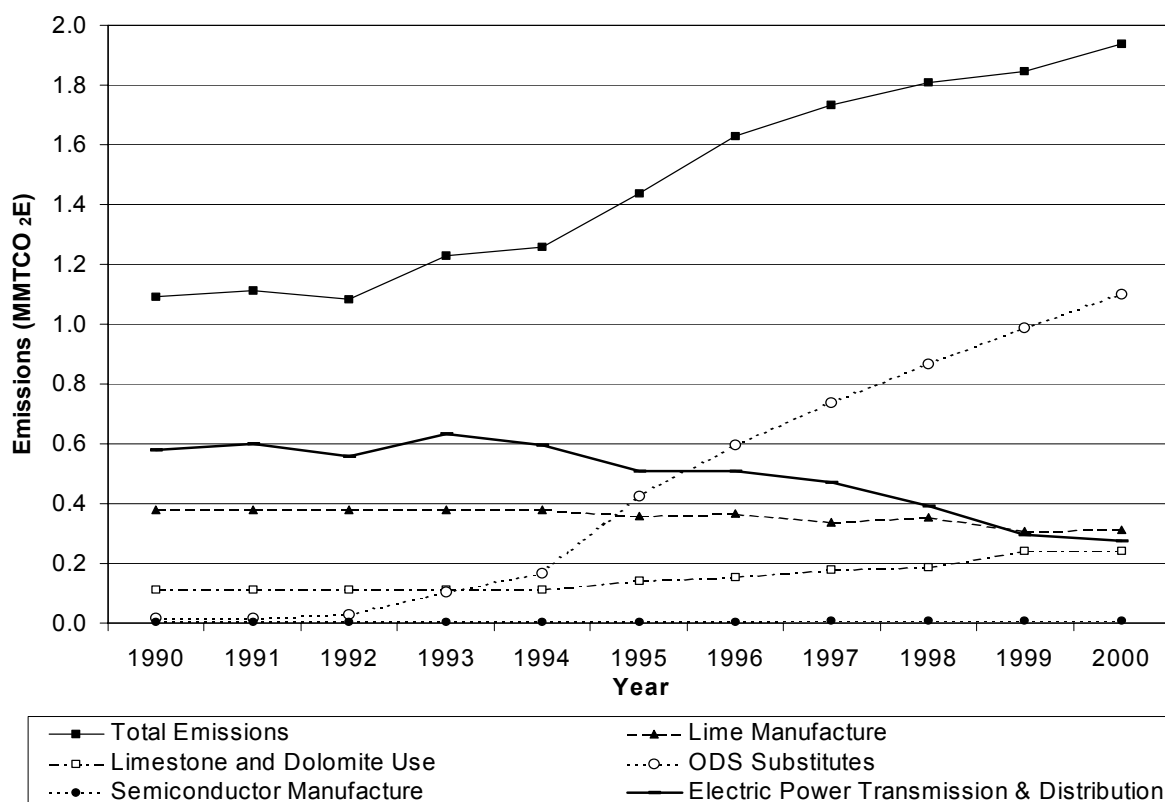
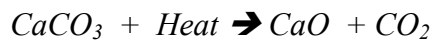


Figure 15. Trends in Greenhouse Gas Emissions from Industrial Processes in Wisconsin for 1990-2000

### 2.2.1. Lime Manufacture

Lime (CaO) is a manufactured product used in steel making, pulp and paper manufacturing, flue gas desulfurization systems at coal-fired electric power plants, construction, and water treatment. Carbon dioxide is generated when limestone is subjected to high temperatures in a kiln to produce calcium oxide (lime):



Lime manufacture accounted for 35% of greenhouse gas emissions from industrial processes in 1990. This percentage was reduced to 16% in 2000. Lime manufacturing emissions decreased by 18% between 1990 and 2000.

#### METHODOLOGY

The methodology used to estimate emissions from lime manufacture follows the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003). The method involves multiplying the amount of lime produced by specific emission factors (0.75 tons CO<sub>2</sub>/tons high-calcium lime produced; 0.86 tons CO<sub>2</sub>/tons dolomitic lime produced).

#### DATA SOURCES

Data on lime production in Wisconsin were obtained from the United States Geological Survey (USGS 2001a). For the years 1990-1993, data were unavailable so data from 1994 were used as a proxy.

### 2.2.2. Limestone and Dolomite Use

Limestone and dolomite are basic raw materials used by metallurgy, chemical, construction, and other industries. Carbon dioxide is emitted during industrial processes which involve heating the compounds, for instance during glass making or metalurgical processes. These materials are also used as sorbants for pollution control systems (EPA 2003). Limestone and dolomite use in Wisconsin accounted for 13% of greenhouse gas emissions from industrial processes in 2000, up from 10% in 1990 as use of these materials is increasing.

#### METHODOLOGY

The methodology used to estimate emissions from limestone and dolomite use follows the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003). The method involves multiplying the limestone and dolomite use data by the respective emissions factors (see Appendix E).

## **DATA SOURCES**

Data on industrial limestone and dolomite use in Wisconsin were obtained from the United States Geological Survey (USGS 2001b). For the years 1990-1993, data were unavailable so data from 1994 were used as a proxy.

### **2.2.3. Consumption of Substitutes for Ozone-Depleting Substances**

Ozone-depleting substances lead to destruction of the earth's stratospheric ozone layer which provides protection from the sun's harmful UV rays. Therefore, an international agreement (the Montreal Protocol, 1987) was made to phase-out these substances. Since these substances are no longer available for use, substitutes in the form of fluorinated gases [hydrofluorocarbons (HFCs), perfluorocarbons (PFCs)] have been created to replace them. These man-made substitutes for ozone-depleting substances (ODS) mitigate the ozone destruction problem but contribute to the problem of global warming. ODSs are used in a variety of applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and sterilization. The use of ODS substitutes increased rapidly (~6000%) during the 1990s and was the largest contributor to greenhouse gas emissions from industrial processes in 2000.

## **METHODOLOGY**

The methodology used to estimate emissions from consumption of ODS substitutes follows the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003). The method involves calculating national per capita emissions of ODS substitutes then multiplying by the state population. National emissions are determined by the U.S. EPA using a 'vintaging' model which predicts ODS and ODS substitute use in the United States based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals and the amount of the chemical required to manufacture and/or maintain equipment and products over time (U.S. EPA 2002). The U.S. EPA, in addressing the uncertainty associated with this method, states that although the model used to estimate emissions is comprehensive, significant uncertainties still exist with regard to levels of equipment sales, characteristics, and emission profiles. At the state level, the uncertainties present at the national level are increased by the use of population to disaggregate national emissions by state. For example, per capita emissions from some equipment, such as motor vehicle air-conditioning or residential air-conditioning, may vary by climate. The number of residences with air-conditioning in states with warm climates is greater than in states with cold climates. Therefore the per-capita emissions should be greater in warmer states. However, the added uncertainty is considered to be minimal, because most of the products that lead to emissions of ODS substitutes are used by consumers throughout the United States (EIIP 2003).

## **DATA SOURCES**

Data on national emissions of ODS substitutes were obtained from the Environmental Protection Agency (USEPA 2003). State and national population data were obtained from the U.S. Census Bureau (2000).

### **2.2.4. Semiconductor Manufacture**

Semiconductor manufacture involves the use of a number of fluorinated gases [PFCs, HFCs, and sulfur hexafluoride (SF<sub>6</sub>)] for plasma etching and chemical vapor deposition processes. Semiconductor manufacture is a minor industry in Wisconsin, therefore emissions from this sector are relatively insignificant, constituting less than 1% of greenhouse gas emissions from industrial processes. However, semiconductor manufacture is a growth industry and emissions from this sector increased by 157% between 1990 and 2000 (see Appendix E).

## **METHODOLOGY**

The methodology used to estimate emissions from semiconductor manufacture follows the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003). The method involves multiplying national emissions by the ratio of the value of state semiconductor shipments to the value of national semiconductor shipments.

## **DATA SOURCES**

Data on national emissions of greenhouse gases from semiconductor manufacture were obtained from the Environmental Protection Agency (USEPA 2003). Data on the value of semiconductor shipments produced at the state and national levels were taken from the U.S. Census Bureau's Economic Census (1997).

### **2.2.5. Electric Power Transmission and Distribution**

The transmission and distribution of electric power results in emissions of SF<sub>6</sub>, the most potent of the greenhouse gases, which is used as an electrical insulator in circuit breakers, gas-insulated substations, and switchgear. Emissions occur as a result of leaks and faulty seals as well as installation and servicing. Emissions from this sector were the largest contributor to total greenhouse gas emissions from industrial processes in 1990 (53%) but only accounted for 14% in 2000. This decrease in the overall contribution to emissions from industrial processes is due both to the decline in emissions from this sector as well as the large increase in the use of ODS substitutes. Independently, emissions from electric power transmission and distribution sector decreased by 53%. This decrease is due to an increase in the price of SF<sub>6</sub> and an increased awareness of its negative environmental impacts.

## **METHODOLOGY**

The methodology used to estimate emissions from semiconductor manufacture follows the methods developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003). The method for estimating emissions from electric power transmission and distribution involves multiplying national SF<sub>6</sub> emissions by the ratio of state electricity consumption to national electricity consumption.

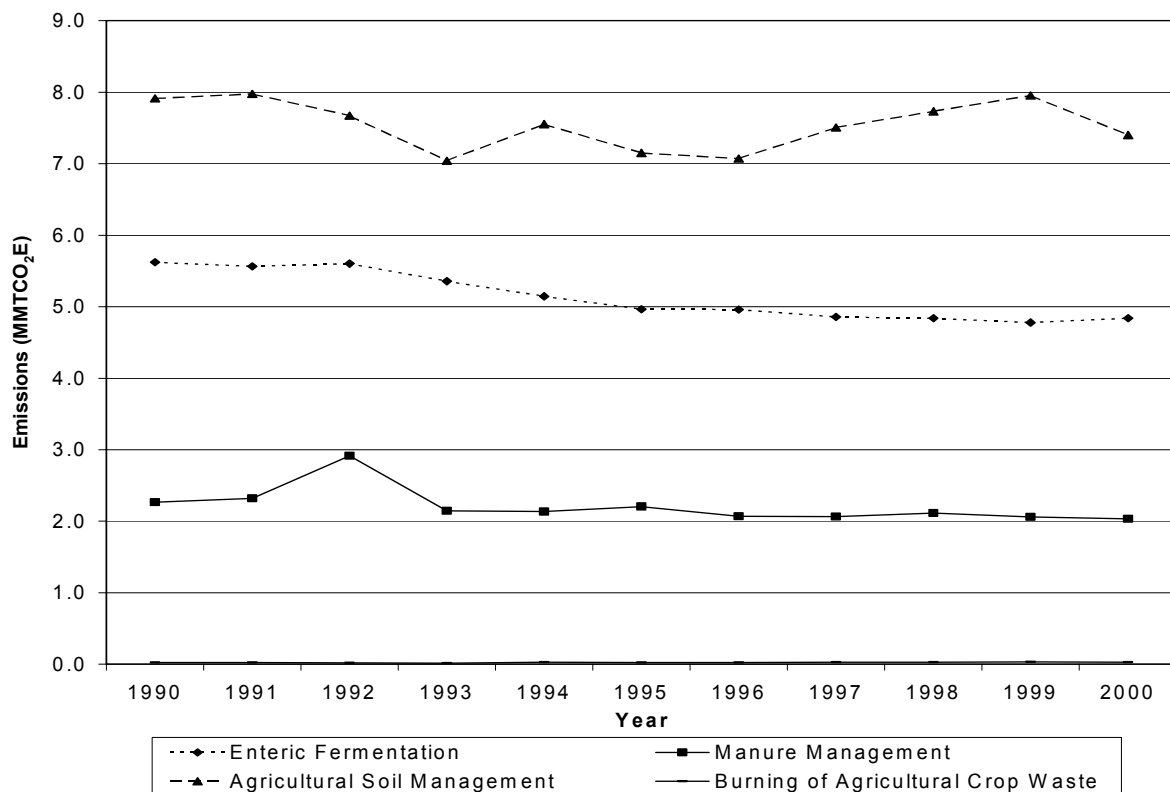
## **DATA SOURCES**

Data on national emissions of SF<sub>6</sub> from the electric utility sector were obtained from the Environmental Protection Agency (USEPA 2003). Data on state and national electricity consumption were obtained from the Energy Information Administration (EIA 2001c).



### 2.3. Agriculture

Agricultural activities, including enteric fermentation, manure management, agricultural soil management, and burning of agricultural crop waste, result in the emission of methane and nitrous oxide to the atmosphere. In Wisconsin, the agricultural sector contributed 14.3 MMTCO<sub>2</sub>E of greenhouse gas emissions in 2000, accounting for 11% of Wisconsin's total greenhouse gas emissions. The largest contributor to overall greenhouse gas emissions within the agricultural sector is agricultural soil management which contributes emissions in the form of nitrous oxide (Figure 16). Enteric fermentation is the second largest contributor to overall greenhouse gas emissions but the largest contributor of methane emissions.



**Figure 16. Greenhouse Gas Emissions (N<sub>2</sub>O and CH<sub>4</sub>) from Agricultural Activities in Wisconsin from 1990-2000**

### **2.3.1. Enteric Fermentation**

Enteric fermentation refers to a digestive process that occurs within the stomachs of certain animals. Microbes ferment food consumed by the animals. Methane is produced as a by-product and subsequently released to the atmosphere via exhalation or eructation. The amount of methane released depends on the amount and type of feed consumed. Ruminant animals, including cattle, bison, sheep, and goats, emit the majority of methane due to the presence of a rumen or fore-stomach in their digestive systems.

Enteric fermentation is the largest source of methane emissions in Wisconsin and the second largest source of agricultural greenhouse gas emissions. Methane emissions from enteric fermentation in Wisconsin have decreased between 1990 and 2000 from 15,821 MMTCO<sub>2</sub>E to 14,301 MMTCO<sub>2</sub>E but have consistently accounted for 33-36% of total greenhouse gas emissions from agriculture. The reduction in emissions parallels a decline in dairy cattle populations in Wisconsin which went from 2536.9 thousand head in 1990 to 1970.9 thousand head in 2000 (USDA-NASS 2002) (see Appendix F). Despite the reduction in numbers, the population of dairy cattle was still larger than the population of any other ruminant animal, thus dairy cattle emitted the greatest amount of methane.

## **METHODOLOGY**

The methodology used to estimate emissions from enteric fermentation is consistent with the methods developed by the Intergovernmental Panel on Climate Change (IPCC 2000) and is described in the EIIP guidance document (EIIP 2003). The method for estimating emissions from enteric fermentation involves multiplying animal populations by their respective emission factors (USEPA 2003) which were developed using methods from IPCC (2000) in conjunction with U.S. EPA's region-specific cattle enteric fermentation model (USEPA 2002). Emissions factors are given in Appendix F.

## **DATA SOURCES**

Data on average animal populations, over the course of the inventory year, for cattle, sheep, goats, swine, and horses were obtained from the USDA's National Agricultural Statistics Service (USDA-NASS 2002). The USDA statistics are included as default data in the State Inventory Tool. These data are generally consistent with state-level data since states are responsible for providing data to the USDA.

### **2.3.2. Manure Management**

The decomposition of livestock manure results in emissions of both methane and nitrous oxide. Methane emissions occur during anaerobic decomposition. Anaerobic conditions are present in liquid manure storage systems (lagoons, ponds, pits, and tanks) and most methane emissions occur under these types of management systems. Manure managed as a solid or deposited on fields is subject to aerobic conditions and therefore releases little or no methane.

Other factors affecting the amount of methane produced include temperature, moisture level, and manure composition.

Nitrous oxide is produced as part of the nitrogen cycle during which nitrogen in manure and urine undergoes nitrification and denitrification. For N<sub>2</sub>O emissions to occur, the manure must first be handled under aerobic conditions where ammonia or organic nitrogen is converted to nitrates and nitrites (nitrification). The manure must then undergo an anaerobic decomposition period where the nitrates and nitrites are reduced to nitrogen gas (N<sub>2</sub>), with intermediate production of nitrous oxide (N<sub>2</sub>O) and nitric oxide (NO) (denitrification) (USEPA 2003). Nitrous oxide emissions are most likely to occur in dry manure management systems which generally have aerobic conditions but can undergo saturation periods. For instance, a cattle drylot system may experience saturated conditions during a rain event. Only nitrous oxide emissions originating from manure in storage systems are accounted for in this section. Other emissions from manure/urine deposited on pastures, ranges, or paddocks, as well as that spread directly on fields, are accounted for under the soil management section.

Methane emissions from manure management in Wisconsin have decreased slightly between 1990 and 2000 (Figure 2.3.1) but have consistently accounted for 14-15% of total greenhouse gas emissions from agriculture. The reduction in emissions parallels a decline in dairy cattle populations in Wisconsin. Nitrous oxide emissions from manure management are negligible in comparison to methane emissions.

## METHODOLOGY

Methods used to estimate emissions from manure management are taken from the Intergovernmental Panel on Climate Change's *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* document (IPCC 2000). The methodology is described in detail in the EIIP guidance document (EIIP 2003).

To estimate methane emissions from manure management, it is necessary to first calculate the amount of volatile solids produced by each animal type using the following equation

$$\text{Total } VS_i \text{ produced (kg/yr)} = \text{Animal}_i \text{ Population (head)} \times \text{TAM}_i \text{ (kg)} \times \text{VS}_i \text{ (kg VS per 1,000 kg animal mass per day)} \times 365 \text{ (days per yr)} / 1,000 \text{ (kg animal mass)}$$

where TAM = total animal mass. Then, methane emissions are estimated using animal specific methane production capacity values (B<sub>oi</sub>) and methane conversion factors (MCF) which account for management system characteristics and climate (USEPA 2003).

$$CH_4 \text{ Emissions for animal } i \text{ (m}^3 \text{ CH}_4\text{)} = \text{VS}_i \text{ (kg/yr)} \times B_{oi} \text{ (m}^3\text{/kg VS)} \times \text{weighted MCF}$$

The emissions estimates are then converted to metric tons of methane, summed across animal types, and finally converted to MMTCO<sub>2</sub>E.

Emissions of nitrous oxide were estimated by first calculating the total nitrogen present in manure managed in each manure management system type using the following formula (USEPA 2003):

$$\text{Nitrogen Excreted by Animal}_i \text{ (kg/yr)} = \text{Population (head)} \times \text{TAM (kg)} / 1,000 \text{ kg} \times \text{Nitrogen Excretion Rate (kg/day/1,000 kg animal mass)} \times 365 \text{ days/yr}$$

Next, the amount of nitrogen in liquid systems and dry systems was calculated, the sum of which will be the total nitrogen from manure that is managed. Finally, multiply the nitrogen from managed animal waste by the appropriate system-specific emission factors (see Appendix F), sum across system types, and convert to the appropriate units to obtain nitrous oxide emissions.

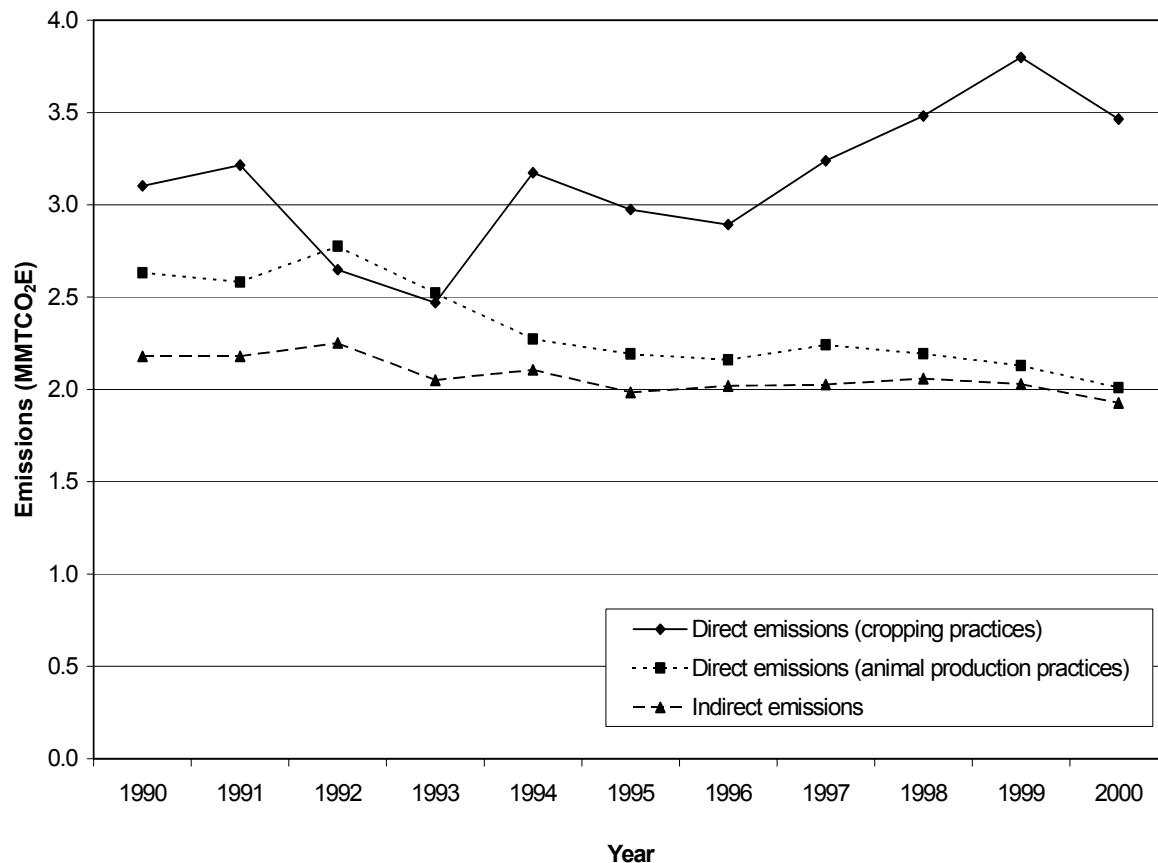
## **DATA SOURCES**

The data used for estimation of emissions from manure management are the same as that used for enteric fermentation. Data on average animal populations, over the course of the inventory year, for cattle, sheep, goats, swine, and horses were obtained from the USDA's National Agricultural Statistics Service (USDA-NASS 2002). The USDA statistics are included as default data in the State Inventory Tool.

### **2.3.3. Agricultural Soil Management**

Nitrous oxide emissions occur as a result of agricultural soil management practices which add nitrogen to the soil where it is subject to microbial nitrification and denitrification processes. There are three categories of nitrous oxide emissions sources associated with agricultural soil management practices: direct emissions due to cropping practices, direct emissions due to animal production, and indirect emissions induced by agricultural applications of nitrogen. Cropping practices resulting in nitrous oxide emissions include fertilizer use, application of manure through daily spread operations, application of sewage sludge, application of crop residues, and production of nitrogen-fixing crops. Animal production practices resulting in nitrous oxide emissions include only the direct deposit of manure by animals in pastures, ranges, and paddocks. Emissions from manure used as commercial fertilizer, applied in daily spread applications, or managed in manure management systems are not included in this section. Indirect emissions induced by agricultural application of nitrogen to soils occur through volatilization, leaching, and runoff of nitrogen.

Emissions of nitrous oxide from agricultural soil management were 6.7 MMTCO<sub>2</sub>E in 2000. Soil management is the largest source within the agricultural sector, accounting for between 47-53% of total greenhouse gas emissions from 1990 to 2000. Direct emissions due to cropping practices is the largest source within soil management (Figure 17).



**Figure 17. Source Categories of Nitrous Oxide Emissions from Agricultural Soil Management in Wisconsin from 1990-2000**

## METHODOLOGY

Methods for estimating nitrous oxide emissions from agricultural soil management were taken from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), the *IPCC Good Practice Guidance* (IPCC 2000), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (USEPA 2003). The methodology is described in detail in the EIIP guidance document (EIIP 2003).

### **Direct Emissions from Agricultural Cropping Practices**

Estimates of direct nitrous oxide emissions from managed soils in Wisconsin were based on the amount of nitrogen deposited annually on managed soils in the following forms: (1) commercial fertilizer application (including sewage sludge); (2) manure application from daily spread operations; (3) production of nitrogen-fixing crops; (4) nitrogen returned to soils through the application of crop residues.

To determine the emissions from commercial fertilizer application, the unvolatilized fraction of applied nitrogen from fertilizer was multiplied by an emission factor, as in the following equations, and then converted to the desired units.

$$\text{Unvolatilized N from Synthetic Fertilizer (kg N/yr)} = \text{Synthetic Fertilizer Used in State (kg N/yr)} \times (1 - 0.1)$$

$$\text{Synthetic Fertilizer Direct Emissions (kg N}_2\text{O-N/yr)} = \text{Unvolatilized N from Synthetic Fertilizer (kg N/yr)} \times 0.0125 (\text{N}_2\text{O-N)/N}$$

Emissions from commercial organic fertilizer application (excluding manure) are calculated in the same manner except that 20% of nitrogen is assumed to volatilize. Examples of organic fertilizers include dried blood, compost, and sewage sludge.

Emissions from manure applied to soils were calculated from the amount of nitrogen in the manure multiplied by the emission factor. The amount of nitrogen in manure is calculated as follows:

$$\text{Nitrogen Excreted by Animal}_i \text{ (kg/yr)} = \text{Pop. of Animal}_i \times \% \text{ of Manure Managed as Daily Spread} \times \text{TAM}_i \text{ (kg)} \times \text{Nitrogen Excretion Rate (kg N/1000 kg Animal}_i\text{/day)} \times 365 \text{ days/yr}$$

Sum the results of this equation across animal types to yield total nitrogen input from animal waste applied as daily spread. Next, adjust the total nitrogen excreted per year to account for the portion that volatilizes to  $\text{NH}_3$  and  $\text{NO}_x$ , i.e., 20 percent (IPCC/UNEP/OECD/IEA 1997).

$$\text{Total Unvolatilized N Excreted (kg/yr)} = \text{Total N Excreted (kg/yr)} \times 0.8$$

Calculate the nitrogen from animal waste systems eventually added to soil, or that nitrogen from animal waste which is not applied as daily spread, using the “Nitrogen Excreted by Animal<sub>i</sub>” equation above but substituting “% of manure not applied as daily spread managed manure” for “% managed as daily spread”.

The following equation was used to calculate emissions from the incorporation of crop residues into the soil:

$$\text{Nitrogen in Crop}_i \text{ Residue (kg N/yr)} = \text{Crop}_i \text{ Production (kg/yr)} \times \text{Mass Ratio of Crop}_i \text{ Residue to Crop}_i \times \text{Dry Matter Fraction for Residue}_i \times \text{Residue Retention Fraction} \times \text{Nitrogen Content of Residue}_i \text{ (kg N/ kg dry biomass)}$$

The results for all crop types are summed and then multiplied by the emission factor 0.0125 kg  $\text{N}_2\text{O-N/kg N}$  and converted to the desired units. It is assumed that all residues from corn, wheat, bean and pulse production, except fractions burned in the field after harvest, are left in the field as residue and incorporated into the soil.

To estimate statewide emissions of N<sub>2</sub>O from N-fixing crops, four steps are performed: (1) obtain data on biomass production of N-fixing crops; (2) calculate total nitrogen input from N-fixing crops; (3) calculate direct emissions from N-fixing crops in N<sub>2</sub>O-N/yr and sum across all crop types; and (4) convert the emissions to units of N<sub>2</sub>O. Total nitrogen input is calculated using the following method.

Nitrogen input from N-fixing crops (such as soybeans, lentils, and peanuts) is calculated as follows:

$$\text{Nitrogen Input from N-fixing Crops (kg N/yr)} = \text{Production of N-fixing crops in State (kg dry biomass/yr)} \times (1 + \text{Residue to Crop Mass Ratio}) \times \text{Residue Dry Matter Fraction} \times \text{Fraction of N in N-fixing Crops (kg N/kg dry biomass)}$$

Nitrogen input from N-fixing forage crops (such as red clover, white clover, etc.) is calculated as follows:

$$\text{Nitrogen Input from N-fixing Forage Crops (kg N/yr)} = \text{Production of N-fixing crops in State (kg dry biomass/yr)} \times \text{Fraction of N in N-fixing Crops (kg N/kg dry biomass)}$$

The values are then summed across all crops to yield the total nitrogen input from N-fixing crops. Direct emissions from N-fixing crops are calculated by multiplying the nitrogen input from all crops by 0.0125 N<sub>2</sub>O-N/N and converting to the desired units.

### **Direct Nitrous Oxide Emissions from Animal Production**

Direct N<sub>2</sub>O emissions from pasture, range, and paddock livestock manure are based on the amount of nitrogen in manure for each animal type. This value is determined from the following equation:

$$\text{Total Nitrogen Excreted by Animal}_i \text{ (kg N/yr)} = \text{Pop. of Animal}_i \times \% \text{ of Manure Deposited on Pastures, Ranges, and Paddocks} \times \text{TAM (kg)} \times \text{Nitrogen Excretion Rate (kg N/1000 kg Animal}_i \text{/day)} \times 365 \text{ (days/yr)}$$

The amount of nitrogen in manure is then multiplied by the IPCC default emission factor, 0.02 kg N<sub>2</sub>O-N/kg N excreted, and the units converted.

### **Indirect Emissions from Nitrogen (N) Applied to Agricultural Soils**

Estimates of indirect nitrous oxide emissions from soils include volatilization of NH<sub>3</sub> and NO<sub>x</sub> from nitrogen applied to agricultural soils through the application of fertilizer and livestock manure as well as leaching and runoff of nitrogen from agricultural fields.

In order to calculate NH<sub>3</sub> and NO<sub>x</sub> volatilization from fertilizer application, the amount of N applied to the soil was multiplied by the fraction of fertilizer N that volatilizes. The IPCC suggests default values of 10 and 20 percent for the fraction of synthetic and organic fertilizer N that volatilizes, respectively (IPCC/UNEP/OECD/IEA 1997). Ammonia and

NO<sub>x</sub> volatilization from animal wastes can be calculated using total N excretion by all livestock in the state. Nitrogen excreted must then be summed across animal types. The total N excretion by livestock is multiplied by 20 percent, the fraction of total manure N that volatilizes. The amount of synthetic N applied to soil that volatilizes and the total N excretion by livestock that volatilizes are summed and the total is multiplied by 0.01 kg N<sub>2</sub>O-N per kg NH<sub>3</sub>-N and NO<sub>x</sub>-N.

Emissions of N<sub>2</sub>O from leaching and runoff were calculated using the following five steps: (1) obtain data on unvolatilized synthetic and organic N applications; (2) estimate leaching and runoff from fertilizer application by multiplying the unvolatilized N by 30%; (3) estimate leaching and runoff from animal waste assuming that 80% of total manure N does not volatilize and that 30% of unvolatilized N enters leachate and runoff; (4) calculate indirect emissions from leaching and runoff in N<sub>2</sub>O-N/yr using the following equation:

$$N_2O \text{ Emissions from L\&R (kg N}_2\text{O-N/yr)} = \text{Total N L\&R (kg N/yr)} \times 0.025 \text{ (kg N}_2\text{O-N/kg N)};$$

and (5) convert the emissions to units of N<sub>2</sub>O.

## DATA SOURCES

Data required for this section include crop production, fertilizer use, and animal populations. Crop production data were obtained from the USDA's National Agricultural Statistics Service (USDA-NASS 2002). Fertilizer use data were obtained from the Wisconsin Department of Agriculture, Trade, and Consumer Protection (WDATCP 2003). Data on animal populations were the same as used in previous sections and were obtained from the USDA's National Agricultural Statistics Service (USDA-NASS 2002).

### 2.3.4. Agricultural Residue Burning

The burning of crop residues is a source of methane and nitrous oxide. Carbon dioxide is also generated but these emissions are not included in emissions estimates because the carbon released as carbon dioxide during burning had been taken up from carbon dioxide in the atmosphere as crops grew, thus resulting in no net emissions.

Emissions from agricultural residue burning in Wisconsin are low, contributing only 0.03 MMTCO<sub>2</sub>E in 2000. This accounts for only a fraction of a percent of the total greenhouse gas emissions contributed by agricultural activities.

## METHODOLOGY

The methods described here were recommended by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OCED/IEA 1997) and are described in detail in the EIIP guidance document (EIIP 2003). First, the amount of dry matter burned is calculated as follows, where burning efficiency is defined as the fraction of dry biomass exposed to burning that actually



burns, and combustion efficiency is defined as the fraction of carbon in the fire that is released to the atmosphere:

$$\text{Amount of Dry Matter Burned (metric tons)} = \text{Annual Crop Production (metric tons)} \times \text{Residue/Crop Ratio} \times \text{Proportion of Crop Produced in Fields where Residue is Burned (\%)} \times \text{Dry Matter Content of the Residue (\%)} \times \text{Burning Efficiency (\%)} \times \text{Combustion Efficiency (\%)}$$

The total amount of carbon released is determined from the following equation and methane emissions are estimated by converting to the appropriate units:

$$\text{Total Carbon Released (metric tons)} = \text{Dry Matter Burned (metric tons)} \times \text{Carbon Content of the Residue (metric tons C/metric tons dry matter)}$$

Emissions of nitrous oxide are estimated by calculating the amount of dry matter burned as above, then multiplying by the nitrogen content of the residue. This value multiplied by the emission factor 0.007 N<sub>2</sub>O-N/N gives the nitrous oxide emissions.

## DATA SOURCES

Data on crop production used in this section were the same as that used in the agricultural soil management section. These data were obtained from the USDA's National Agricultural Statistics Service (USDA-NASS 2002).

### 2.4. Land-Use Change and Forestry

Land-use change and forestry alter fluxes of carbon dioxide in the biosphere, including the withdrawal of carbon dioxide from the atmosphere by vegetation via photosynthesis and the return of carbon dioxide to the atmosphere by respiration of vegetation and decay of organic matter in soils/litter. Therefore, changes occur in the amount of carbon stored in vegetation, litter, and soil, leading to either the release of carbon dioxide to the atmosphere or the sequestration of carbon in biomass. This section deals with activities that either change the way land is used or affect the amount of biomass existing in biomass stocks. Specifically, this section includes estimates of the net carbon dioxide (CO<sub>2</sub>) flux caused by land-use change and forestry activities including (1) changes in agricultural soil carbon stocks from liming of agricultural soils; (2) changes in yard trimming carbon stocks in landfills; and (3) changes in forest carbon stocks.

Liming of agricultural soils involves adding lime, in the form of crushed limestone, and dolomite to agricultural soils to inhibit acidification. These compounds degrade once they come in contact with acid soils, generating CO<sub>2</sub> emissions. The rate of degradation is dependent on soil conditions and the type of mineral being applied. Agricultural soils are also important sources of other greenhouse gases, particularly nitrous oxide from application

of fertilizers, manure, and crop residues and from cultivation of legumes. These emissions are accounted for in the Agriculture chapter.

Landfilled yard trimmings can store carbon indefinitely. Thus, landfilling the carbon in the trimmings effectively offsets emissions by sequestering the carbon and not allowing it to be released to the atmosphere.

Forest stocks (biomass, coarse woody debris, wood products in use, and landfilled wood products) also sequester carbon. As trees grow, they remove carbon from the atmosphere and store it in living tree biomass. Trees continue to accumulate carbon as they age but become relatively constant carbon stores once they reach maturity. Dying trees deposit litter and debris on the forest floor, where it undergoes the decay process during which carbon is released to the atmosphere and also added to the soil. The net change in forest carbon is not equivalent to the net flux between forests and the atmosphere because timber harvests may not immediately release carbon to the atmosphere. Harvesting transfers carbon from one of the forest carbon storage pools to a "product pool." Once in a product pool, the carbon is emitted over time as CO<sub>2</sub> if the wood product combusts or decays.

Land-use change and forestry were responsible for sequestering 22 MMTCO<sub>2</sub>E throughout Wisconsin in 2000. This is less than the amount sequestered in 1990 (23 MMTCO<sub>2</sub>E). Though sequestration in the biomass and soil pools remained constant, less carbon was sequestered by landfilling of yard trimmings and wood products. In addition, carbon emissions from forest floors and coarse woody debris increased. Biomass was the largest carbon sink while forest floors and coarse woody debris was the largest source.

## **METHODOLOGY**

The methods for this section are described in detail in the EIIP guidance document (EIIP 2003). Determination of emissions from liming of agricultural soils involved multiplying the total limestone applied to soils by the emission factor (0.12 ton C / ton limestone; 0.13 ton C / ton dolomite). Emissions from the landfilling of yard trimmings were calculated by multiplying the tons of yard trimmings landfilled by the emission factor (0.2082 MTCE / ton landfilled yard trimmings). Determination of forest carbon flux involved taking the USDA Forest Service estimates of state forest carbon stocks in 1987, 1992, and 1997 for biomass, forest floors and coarse woody debris, soils, and wood products and landfills. The change in carbon stocks between 1987-1992 and 1992-1997 were divided by five to determine the average annual change. The 1992-1997 average annual change was used as a proxy for 1998-2000. The average annual changes for each category were summed to determine the total annual change.

## **DATA SOURCES**

All data in this section were provided as default data in the State Inventory Tool. Data on total limestone applied to soils were taken from the USGS Minerals Yearbook, "Stone, Crushed" (USGS 2001c). Data on landfilled yard trimmings were from annual surveys

conducted by Biocycle magazine and from the U.S. EPA's report on Municipal Solid Waste in the United States (EIIP 2003). Forest carbon flux data were from the USDA Forest Service (EIIP 2003).

## **2.5. Waste**

Waste management activities result in emissions of methane, carbon dioxide, and nitrous oxide. Specifically, waste management results in methane emissions from landfills, carbon dioxide and nitrous oxide emissions from waste combustion, and methane and nitrous oxide emissions from wastewater treatment. Methodologies are not currently available to provide a complete estimate of nitrous oxide emissions from wastewater, thus only nitrous oxide emissions from human sewage in wastewater are included in this inventory.

Emissions from waste management in Wisconsin equaled 3.7 MMTCO<sub>2</sub>E in 2000, down from 4.3 MMTCO<sub>2</sub>E in 1990. This reduction is largely due to the recovery of methane emissions from landfills.

### **2.5.1. Municipal Solid Waste – Landfills**

Methane emissions from landfills result from the decomposition of organic materials. Initially, organic waste is digested by aerobic bacteria. However, oxygen sources eventually run out and anaerobic bacteria take over. The remaining waste is ultimately broken down into growth substrates used by methanogenic bacteria. These are converted by methane-producing bacteria into stabilized organic materials and biogas composed of 50% carbon dioxide and 50% methane by volume. Factors influencing the amount of methane emitted from landfills include the quantity and composition of waste less than 30 years old. Methane gas can be flared or recovered and used for energy, a practice that has been increasing in recent years.

Carbon dioxide generated from the decomposition of biogenic waste is not included in emissions estimates as organic materials derived from biomass sources, such as crops and forests, are assumed to be grown and harvested on a sustainable basis. This implies that the photosynthesis which removes carbon dioxide from the atmosphere is equal to decomposition which adds carbon dioxide to the atmosphere, resulting in zero net emissions. Carbon in landfills that is not converted to carbon dioxide or methane, as in the case of wood products and yard trimmings, is effectively in long-term storage or, in other words, sequestered. Sequestration is only possible in the case of biogenic carbon. Non-biogenic carbon, such as plastic, represents a transfer from one long-term carbon pool to another rather than removal from the carbon cycle.

Landfills are the second largest source of methane emissions in Wisconsin, after cows, contributing on average 76% of total greenhouse gas emissions from waste management. The percentage of emissions attributable to landfills has decreased from 1990-2000 as has the

absolute amount of methane emissions which was at 2.8 MMTCO<sub>2</sub>E in 2000, down from 3.4 MMTCO<sub>2</sub>E in 1990. Despite the overall decrease between 1990 and 2000, the lowest emissions level was reached in 1996 and emissions have been increasing between 1996 and 2000 (see Appendix H). This trend is explained by the slowed rate of increase in the amount of methane flared or recovered. Both the amount of waste generated and the amount of methane flared / recovered have increased from 1990-2000. Increases in the amount of methane flared / recovered were large enough to offset an increase in methane emissions corresponding to increased waste generation in the early 1990s. During the late 1990s, the growth in methane flaring / recovery slowed and methane emissions began to increase, though remaining below 1990 levels.

## METHODOLOGY

The approach used to estimate methane emissions from landfills is based on an emissions model developed for the report *Anthropogenic Methane Emissions in the United States: Report to Congress* (USEPA 1993). The methods are described in detail in the EIIP guidance document (EIIP 2003).

Estimating methane emissions from landfills involves twelve steps:

- 1) Obtain required data on annual waste disposal, numbers of large and small landfills, and quantities of landfill methane recovered or flared;
- 2) Estimate waste in place (WIP) at Municipal Solid Waste (MSW) landfills;
- 3) Estimate fraction of waste in place in large versus small landfills;
- 4) Classify state as non-arid or arid based on average annual rainfall (Wisconsin is non-arid);
- 5) Estimate the amount of methane generated from waste in place at small MSW landfills using a climate specific emission factor:  

$$\text{Non-arid: } CH_4 (\text{tons/year}) = 0.002695 \text{ tons } CH_4/\text{yr/ton WIP} \times \text{WIP (tons)}$$
- 6) Estimate the amount of methane generated from waste in place at large MSW landfills using a climate specific emission factor:  

$$\text{Non-arid: } CH_4 (\text{tons}) = (\text{Number of large landfills} \times 3,218 \text{ tons } CH_4) + [0.002002 \text{ tons } CH_4/\text{yr/ton WIP} \times \text{WIP (tons)}]$$
- 7) Estimate total methane generation from MSW landfills by summing the results of the above two calculations;
- 8) Adjust MSW methane generation for flaring and recovery i.e. subtract the amount recovered and burned;
- 9) Adjust MSW methane generation for oxidation assuming that 10% of methane generated is oxidized in the soil;
- 10) Estimate the amount of methane generated from industrial landfills assuming emissions are 7% of methane emissions from MSW landfills based on the U.S. EPA's national – level estimate (1993);
- 11) Sum MSW and industrial methane generation; and
- 12) Convert units to metric tons of carbon equivalent (MTCE).

## DATA SOURCES

Data on annual waste disposal and the number of large/small landfills from 1990-2000 in Wisconsin were obtained from the Department of Natural Resources Bureau of Waste Management. Annual waste disposal quantities for 1969-1989 were estimated based on state population and national trends. Quantities of landfill methane recovered or flared were obtained from the Wisconsin Division of Energy's Energy Resources Section.

### 2.5.2. Municipal Solid Waste - Combustion

Combustion of municipal solid waste results in emissions of carbon dioxide and nitrous oxide. Carbon dioxide emitted from the burning of biomass (wood) is not included in emissions estimates, as discussed previously. However, burning of plastics, textiles, and synthetic rubber results in carbon dioxide emissions that are included in emissions estimates.

Very little waste combustion takes place in Wisconsin. Hence, emissions from this category are very low with nitrous oxide emissions at 0.03 and carbon dioxide emissions at 0.04 MMTCO<sub>2</sub>E. Nitrous oxide emissions have remained constant from 1990-2000. Carbon dioxide emissions, on the other hand, have increased as consumption of plastic materials and synthetic fibers is on the rise.

## METHODOLOGY

Estimation of emissions from waste combustion involves determining the quantity of municipal waste combusted, estimating the carbon dioxide and nitrous oxide emissions from combustion of municipal waste using the respective emission factors, and converting to the appropriate units. The emission factors for carbon dioxide emissions are based on national proportions of fossil-fuel derived materials (plastics, synthetic rubber, and synthetic fibers) combusted, their carbon content, and the fraction oxidized. Therefore, carbon dioxide emissions are determined for each material and summed to obtain total carbon dioxide emissions as per the following equation:

$$CO_2 \text{ Emissions} = [Tons \text{ MSW Combusted} \times \text{Emission Factor (Plastic)}] + [Tons \text{ MSW Combusted} \times \text{Emission Factor (Synthetic rubber)}] + [Tons \text{ MSW Combusted} \times \text{Emission Factor (Synthetic fiber)}]$$

Determination of nitrous oxide emissions requires simply multiplying the tons of MSW combusted by an emissions factor of 0.0001 tons nitrous oxide / ton MSW combusted, then converting to the appropriate units.

## DATA SOURCES

Data on the tonnage of waste combusted in Wisconsin were obtained from the Wisconsin Department of Natural Resources Air Management Program's Air Emissions Management System (AEMS) database.

### 2.5.3. Municipal Wastewater

Treatment of municipal wastewater can result in emissions of both methane and nitrous oxide. Methane is released via anaerobic degradation of organic material which occurs in sewage treatment plants. Wastewater streams with higher organic content will produce more methane. Nitrous oxide emissions are a product of nitrification and denitrification processes that occur in wastewater containing nitrogen-rich organic matter.

Total greenhouse gas emissions from wastewater treatment in Wisconsin were 0.9 MMTCO<sub>2</sub>E in 2000, an increase of 0.1 MMTCO<sub>2</sub>E since 1990. Industrial wastewater was the source of approximately half of the emissions due to the presence of a large pulp and paper manufacturing industry in Wisconsin. Municipal wastewater contributed the remaining half of total emissions.

## METHODOLOGY

The methodology used in this section was taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and is described in the EIIP guidance document (EIIP 2003).

To estimate methane emissions from municipal wastewater:

- (1) Obtain required data including state population, kilograms (kg) BOD<sub>5</sub> per capita per day, and the fraction of total wastewater that is treated anaerobically;
- (2) Estimate total biochemical oxygen demand (BOD<sub>5</sub>) produced:

$$BOD_5 \text{ Generated (kg/day)} = \text{Population} \times BOD_5 \text{ Generation Rate (kg/capita/day)}$$

- (3) Estimate annual quantity of BOD<sub>5</sub> treated anaerobically using the following equation where the fraction of wastewater BOD<sub>5</sub> treated anaerobically is 16.25% (USEPA 2002):

$$\text{Annual BOD}_5 \text{ Treated Anaerobically (kg/yr)} = BOD_5 \text{ Generated (kg/day)} \times \text{Fraction of Wastewater BOD}_5 \text{ Treated Anaerobically (\%)} \times 365 \text{ (days/year)}$$

- (4) Estimate gross annual methane emissions from wastewater treatment:

$$CH_4 \text{ Emissions (kg } CH_4) = BOD_5 \text{ Treated Anaerobically (kg } BOD_5/\text{yr}) \times 0.6 \text{ (kg } CH_4/\text{kg } BOD_5)$$

- (5) Convert annual methane emissions from wastewater to metric tons of carbon equivalent (MTCE):

$$CH_4 \text{ Emissions (MTCE)} = CH_4 \text{ Emissions (kg } CH_4) \times 0.001 \text{ metric tons/kg} \times CO_2 \text{ to C Conversion Factor} \times \text{Methane Global Warming Potential}$$

where:  $CO_2$  to C Conversion factor = 12/44  
Methane Global Warming Potential = 21

To estimate nitrous oxide emissions from wastewater:

- (1) Obtain required data on annual per capita protein consumption, the fraction of N in protein, and state population;
- (2) Estimate annual per capita consumption of nitrogen in protein based on U.S. per capita protein consumption (USEPA 2002) and a fraction of N in protein of 16 percent (IPCC/UNEP/OECD/IEA 1997):

$$\text{Per Capita Consumption of N in Protein (kg)} = \text{Per Capita Protein Consumption (kg)} \times N \text{ in Protein (\%)}$$

- (3) Estimate the state's annual consumption of nitrogen in protein:

$$\text{Annual Consumption of N in Protein (kg N)} = \text{Consumption of N in Protein (kg/capita)} \times \text{Population}$$

- (4) Estimate the state's annual nitrous oxide emissions from wastewater treatment using the following equation where the emission factor is 0.1 kg  $N_2O$ -N/kg N:

$$\text{Annual Emissions of } N_2O \text{ from Wastewater (kg } N_2O) = \text{Annual Consumption of N in Protein (kg N)} \times \text{Emission Factor (kg } N_2O\text{-N/kg N)} \times N_2O \text{ to N Conversion Factor}$$

where the  $N_2$  to  $N_2O$  Conversion Factor = 44/28

- (5) Convert annual nitrous oxide emissions from wastewater treatment to metric tons of carbon equivalent by multiplying the  $N_2O$  emissions by the global warming potential for  $N_2O$ , which is 310.

To estimate methane emissions from industrial wastewater:

- (1) Obtain required data including pulp & paper, fruit & vegetable, and red meat & poultry production, oxygen demand from organic or inorganic material in the wastewater

(expressed as Chemical Oxygen Demand, or COD), and the fraction of wastewater treated anaerobically;

- (2) Calculate annual wastewater production for each industry (see Appendix H):

$$\text{Wastewater Production (liters)} = \text{Production (metric tons/yr)} \times \text{Wastewater Produced per Metric Ton of Product (m}^3\text{/metric ton)} \times 1,000 \text{ (l/m}^3\text{)}$$

- (3) Calculate methane emissions for each industry (see Appendix H for industry specific fraction of COD anaerobically treated and emission factors):

$$\text{CH}_4 \text{ Emissions (g CH}_4\text{)} = \text{Wastewater Production (l)} \times \text{COD (g COD/l)} \times \text{Fraction of COD Anaerobically Treated (\%)} \times \text{Emission Factor (g CH}_4\text{/g COD)}$$

- (4) Calculate total methane emissions by summing emissions from each industry;
- (5) Convert methane emissions to metric tons of carbon equivalent by multiplying methane emissions by the global warming potential of 21.

## **DATA SOURCES**

Calculation of methane and nitrous oxide emissions from municipal wastewater required information on state population which was obtained from the U.S. Census Bureau (2000). Data on pulp and paper production were obtained from the Wisconsin Paper Council and data on fruit & vegetable and red meat & poultry production were obtained from the U.S. Department of Agriculture 2002 report on agricultural statistics for Wisconsin (USDA-NASS 2002).



### 3. CONCLUSIONS

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Total net greenhouse gas emissions for Wisconsin were 107.6 MMTCO<sub>2</sub>E in 2000 as estimated by the State Inventory Tool developed for the State and Local Climate Change Program of the Environmental Protection Agency. Wisconsin experienced a 20% growth in gross emissions from 1990 to 2000. The growth seen in Wisconsin was larger than that seen across the nation as a whole, for which emissions increased 15% from 1990 to 2000. Yet, the 20% increase is less than the 28% projected increase in emissions forecast by the Wisconsin Department of Natural Resources in a 1996 study (WDNR 1996).

Carbon dioxide is the predominant greenhouse gas emitted in Wisconsin, accounting for 83% of total gross emissions in 2000. Methane and nitrous oxide each accounted for 8% of total gross emissions, while HFC, PFC, and SF<sub>6</sub> contributed the remaining 1%.

Energy-related activities provide the largest contribution to Wisconsin's greenhouse gas emissions, accounting for 85% of total GHG emissions in 2000. Carbon dioxide emissions from fossil fuel combustion contributed the vast majority of emissions from energy-related activities at 98%. The electric utility sector accounted for 40% of carbon dioxide emissions from fossil fuel combustion in 2000, an increase of 29% since 1990, with the majority of the electricity being used by the industrial sector, the largest 'end-use' contributor of emissions. The transportation sector also contributed a significant portion of CO<sub>2</sub> emissions from fossil fuel combustion at 28%. Coal is the primary fuel source for the electric utility sector while petroleum fuels the transportation sector.

Though industrial processes do not contribute large amounts of greenhouse gas emissions to the atmosphere in Wisconsin in comparison to fossil fuel combustion, the consumption of substitutes for ozone-depleting substances is increasing rapidly as are the resultant emissions. In contrast to this trend, emissions from the agriculture sector decreased during the 1990s. The agricultural sector was the largest source of both methane and nitrous oxide, with emissions of the former stemming from enteric fermentation and the latter resulting from soil management. Emissions from waste management also decreased during the 1990s, primarily due to an increase in the amount of methane recovered from landfills. A decrease was also seen in the amount of carbon sequestered in Wisconsin's forests. Therefore, while emissions of greenhouse gases in Wisconsin were on the rise during the 1990s, sequestration of these emissions was on the decline.

The growth in energy use and the continued dependence on coal has propelled significant growth in Wisconsin's greenhouse gas emissions, the rate of which exceeds that of the United States as a whole. Given the increasing demand for energy among a growing population and expanding economy, it is becoming increasingly important to incorporate energy efficiency and conservation measures and to use sustainable energy sources to minimize Wisconsin's contribution to greenhouse gas emissions. Wisconsin will not only need to reduce emissions from electric utilities, it will also need to address the increase in the consumption of petroleum for motor vehicle transportation. Creative solutions will be

needed to encourage the use of more fuel-efficient vehicles and alternative fuels as well as the use of public transportation.

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